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THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

CLASS 2 ENGINE INFORMATION

A STUDY OF COMPOSITE PROPULSION SYSTEMS FOR ADVANCED LAUNCH VEHICLE APPLICATIONS

[redacted]

VOLUME SEVEN

Report 25,194

Contract NAS7-377

The Marquardt Corporation
Van Nuys, California

September 1966

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FOREWORD

This report constitutes a portion of the final report documentation under National Aeronautics and Space Administration Contract NAS7-377. This and two companion reports (Refs. 1 & 2) present general engine data derived from the study which are organized to facilitate their incorporation into concurrent and subsequent advanced systems studies.

Covered here are the Class 2 Engines (two in number) studied in the program's concluding phase. More complete study results relating to these engine concepts, including such areas as subsystem design trade-off studies and overall vehicle/mission analyses, are given in the main body of the project report (Reference 3).

The present Volume is one of seven in the total published study documentation. Its orientation in the report sequence is shown below:

Volume 1	Summary Report
Volume 2	Main Technical Report, Part 1
Volume 3	Main Technical Report, Part 2
Volume 4	Class 0 Fact Sheets, Part 1
Volume 5	Class 0 Fact Sheets, Part 2
Volume 6	Class 1 Engine Information
→ Volume 7	Class 2 Engine Information

ACKNOWLEDGEMENT

This report results from the contributions of the following Marquardt Science and Technology Group personnel under National Aeronautics and Space Administration Contract NAS7-377:

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Acknowledgement is extended to C. H. Carlson and R. E. Brewster of Marquardt's Product Operations Group who generated the supersonic combustion ramjet (SCRAMJET) performance data incorporated in this report. Appreciation is also expressed to A. Malek and A. J. Hayek of the same organization for assistance in defining approaches for engine structural design and cooling.

The contributions of Rocketdyne, a Division of North American, Incorporated in the area of the primary rocket subsystems design effort is noted. Lockheed California Company provided vehicle integration support which permitted engine sizing and configuration selection for the vehicle model considered here. The assistance of Rocketdyne and Lockheed was received via Marquardt subcontracts under Contract NAS7-377.

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PREFACE

This report comprises a major portion of the technical results of the Class 2 study phase of National Aeronautics and Space Administration Contract NAS7-377, "A Study of Composite Propulsion Systems for Advanced Launch Vehicle Applications". This phase of the program was conducted under Task IV (of four) of the contract work statement.

Composite cycle launch vehicle engines, as defined for this study, are single integrated propulsion systems which are comprised of both rocket (liquid-propellant) and airbreathing subsystems, e.g., primary bipropellant combustors, inlets. To date this type of powerplant has received little systematic study wherein common ground rules are employed to judge the possible merits of the large number of candidate engines.

The potential advantages offered by the more attractive composite systems in advanced (reusable) vehicles include the following points: high payload performance (exceeds the advanced rocket, roughly equals the turbomachine-type airbreather), high operational flexibility across the reusable-cycle mission profile, ease of development in terms of the indicated major facility requirement for competing pure-airbreathing engines (composite engines can be segmented to fit existing or planned ground test facilities which provide high simulated Mach number airflow capability).

It is the objective of the study to (1) appraise this potential for advanced, reusable launch vehicle applications, and (2) provide technical guidance for initiating possible research and development efforts directed toward the ultimate creation of these systems. The study included consideration of both single and multistage vehicles, for earth-orbit payload delivery. The study concentrated on launch vehicles in the 1,000,000 pound gross weight class which operate on hydrogen/oxygen propellants. In general, the study was directed toward propulsion system first availability in the period 1975-1985 and full mission-cycle propulsion requirements from lift-off to landing was considered. The principal performance criteria for engine ranking purposes was payload-in-orbit to gross weight ratio. Other criteria were, however, brought into play as appropriate.

Marquardt, prime contractor, Rocketdyne and Lockheed were associated in this analytical and design study effort. The study was extended over nine (9) months with a final report (of which the present report is Volume 7 of seven) submitted to distribution in February 1967.

INTRODUCTION

GENERAL

This report is the third in a series of three, which specifically present engine information derived from the NASA-contracted study, "A Study of Composite Propulsion Systems for Advanced Launch Vehicle Applications" (NAS7-377). The three reports (the other two are Refs. 1 and 2) are associated with the three chronological phases of the study and comprise varying numbers of engine concepts and various degrees of technical penetration as follows:

Report Order	Associated Study Phase	Number of Engines Included	Technical Penetration
1 (Ref. 1)	Class 0	36	Overall System Analysis only, performance on three (3) reference trajectories based on "ideal" inlet, important parameters "bracketed" only
2 (Ref. 2)	Class 1	12	Included subsystem considerations, performance presented in map form, based on realistic inlets, conceptual designs made, important engine variables exercised parametrically
3 (This Report)	Class 2	2	Effect of varying subsystem and component efficiencies and operational points assessed, performance maps broadened and refined, detailed conceptual designs rendered based on vehicle-stipulated sizing parameters, approaches for structural and thermal design and engine control investigated.

To this end the present report presents detailed working information on two (2) engine concepts taken from both the initial candidate listing of 36 concepts reported in Ref. 1, and the twelve (12) engine types further treated in Ref. 2.

The next section will briefly review the two engine concepts. Also the scope and content of this report will be summarized prior to the two major engine-oriented sections of the document.

BACKGROUND

Of the thirty-six (36) engines originally ordered within the Class 0 phase study (Ref. 1), twelve (12) were selected for further study as Class 1 systems. These twelve (12) systems can be viewed as variations about a single "parent" multimode composite engine concept; the afterburning cycle, air augmented rocket/ramjet system:

SELECTED CLASS 1 ENGINES

(12 SELECTED FROM 36 CANDIDATES)

AFTERBURNING CYCLE AIR AUGMENTED ROCKET/RAMJET PROPULSION SYSTEMS

- → NON AIR LIQUEFACTION SYSTEMS (FOUR ENGINES)
- → AIR LIQUEFACTION SYSTEMS (EIGHT ENGINES)

The basic split shown is that of higher performance air liquefaction systems versus the somewhat simpler non-air liquefaction systems which effects a grouping of eight (8) and four (4), respectively. Both sub-families are represented in previous engine types studied by The Marquardt Corporation in the guise of lightweight, efficient acceleration and cruise aircraft power-plants. These are the Ejector Ramjet systems (non-air liquefaction) and the RamLACE systems (air liquefaction). These "parent" engines are further described in Ref. 2. Design and performance data for the twelve (12) Class 1 Engines, in essence, comprise Ref. 2.

SELECTED CLASS 2 ENGINES

The two engine concepts selected for the Class 2 studies were:

Supercharged Ejector Ramjet (SERJ - Engine No. 11)
SCRAMLACE (Engine No. 22)

With reference to the Class 1 Selection summary given above, it can be seen that a continuation of the duality: non-liquefaction/liquefaction engines, reflected in the Class 1 selection, was also carried forward into Class 2. That is, both an air-liquefaction engine (No. 22) and a non-liquefaction engine (No. 11) were further appraised. Each of these is clearly a better performer in its category, where at the same time additional complexity, e.g., recycled hydrogen, brought only modest gains in payload for the mission model used. The significant advantage of the Supercharged Ejector Ramjet over the basic Ejector Ramjet was notable. This caused it to be chosen as a Class 2 system despite the additional hardware implication of the fan sub-system. The Class 2 Engines are summarily characterized in this table:

SELECTED CLASS 2 ENGINES

Supercharged Ejector Ramjet (SERJ, Engine No. 11)

Attractive Payload Potential with Minimum Technology Uncertainties - Providing a Nearer Term Availability

ScramLACE (Engine No. 22)

Maximum Payload Potential via the Combination of Air Liquefaction and Supersonic Combustion Ramjet Operating Modes, which are not fully Developed Technologies

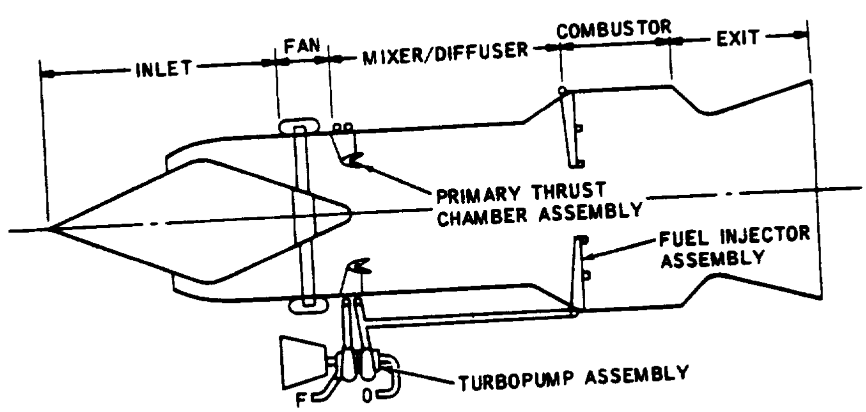
THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

As can be inferred from this listing, the concept of having two packages of varying technical risk is apparent in the engines selected. Engine 11, does represent a significant improvement in potential over the baseline rocket in a concept that has little technical risk associated with it. On the other hand, the Engine 22 represents a considerably higher payload gain. However, two technological risk areas are apparent: (1) the air liquefaction process and, (2) the SCRAMJET mode operation. These selected engines for the Class 2 study are schematically shown and further discussed in the following pages.

<u>SUPERCHARGED EJECTOR RAMJET</u> (SERJ - Engine No. 11)

The supercharged Ejector Ramjet schematically is shown here as a basic Ejector Ramjet which has mounted before the mixing section a low to moderate pressure ratio, thin profile low blockage fan subsystem. In concept, the fan can be driven by either an airbreathing or a bipropellant gas generator. The fan acts to supercharge the basic cycle in the initial acceleration mode thereby improving its specific impulse while reducing the rocket subsystem sizing. Perhaps most important, it provides a mode of operation for low speed flyback-to-base via a ducted fan mode with or without plenum burning. (This would be accomplished by relighting the afterburner at various degrees of lean burning up to stoichiometric.)

SUPERCHARGED EJECTOR RAMJET - ENGINE NO. 11



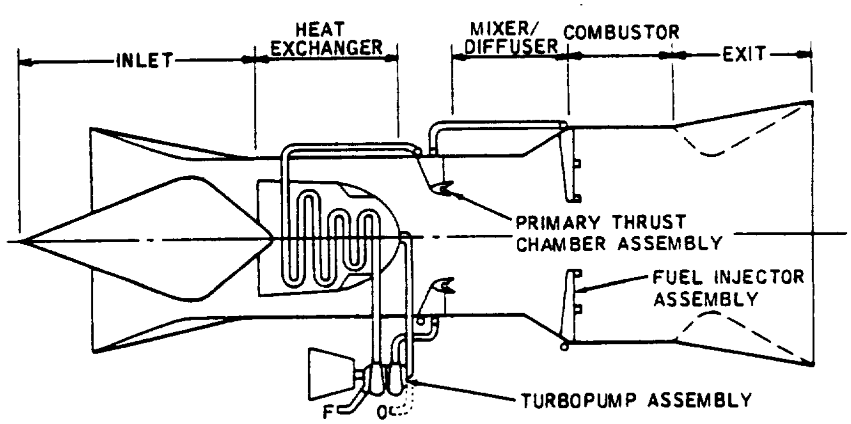
This engine is capable of operating in four discrete modes: (1) supercharged ejector mode, (2) fan ramjet mode, (3) subsonic combustion ramjet and (4) fan only operation. The later operating mode is a low-thrust capability applicable to the flyback and loiter aspect of the mission profile. The engine consists of a single stage low pressure ratio fan capable of being retracted from the main engine flow stream. Accompanying the tip turbine fan is a fan drive subsystem consisting of a remote airbreathing gas generator, or small turbojet engine. Following the fan, a primary rocket subsystem, mixer, diffuser, afterburner, and variable geometry exit nozzle are included as in the basic ejector ramjet engine.

For a typical mission profile the engine is initially operated in the supercharged ejector mode wherein the fan operates at design speed. The stoichiometric primary rockets are operated at full thrust condition and the afterburner operates stoichiometrically. At a flight condition in the approximate vicinity of Mach 1 the primary system can be phased off, the engine continuing in the fam ramjet mode (technically a high bypass ratio, full plenum burning turbofan cycle). In the vicinity of Mach 2 plus, fan operation is stopped and the fan is hinged forward and retracted from the flow stream. The engine continues in the subsonic combustion ramjet mode to the staging condition. Following entry and cruise-back in the subsonic combustion ramjet mode, subsonic loiter and landing is accomplished with fan only operation with little if any plenum burning.

<u>SCRAMLACE</u> (Engine No. 22)

The SCRAMLACE is schematically represented as having inlet and exit configurations which are compatible with the SCRAMJET mode operation. The heat exchanger subsystem shown here in the engine flow passage will from practical considerations be located external to the throughput area of the powerplant as will be noted in the conceptual design drawing provided herein.

SCRAMLACE - ENGINE NO. 22



[redacted]

This engine is capable of three operating modes*: (1) liquid air cycle ejector mode, (2) subsonic combustion ramjet and (3) supersonic combustion ramjet. The engine consists of a primary rocket subsystem which operates on liquid hydrogen and liquid air, with the liquid air being supplied from the air liquefaction unit, consisting of a precooler and condenser. The refrigerant is the liquid hydrogen total flow supplied to the engine. Following the primary rocket section is the mixer, diffuser, afterburner and variable geometry exit nozzle.

Initial engine operation is in the ejector mode with full thrust operation of the primary rockets at a stoichiometric condition. Air flow, nominally constant, is controlled by hydrogen flow into the engine and the specific flight conditions, non primary fuel being burned in the afterburner at a significantly fuel rich condition. At an appropriate flight Mach number the primary rocket subsystem is shut down and the air liquefaction unit is closed off from the inlet diffuser. The engine continues to operate with stoichiometric combustion in the afterburner as a subsonic combustion ramjet. At approximately Mach 6 the engine transists into supersonic combustion ramjet operation by simultaneous shifting of combustion forward into the region of primary rockets (the rockets are not reignited) and full opening of the aft end of the engine to permit the normal shock system to pass from the engine. Upon entry, flyback is nominally accomplished in the subsonic ramjet mode with loiter and landing being achieved in the liquid air cycle ejector phase operation.

It might be noted here that the geometric criteria for efficient mixing of fuel in the SCRAMJET mode are approximately the same as those involved in the rocket/air mixing phase for the ejector mode. This implies that the physical geometry of the rocket structure might in fact be compatible with the SCRAMJET fuel injection requirement. The presence of the primary rocket subsystem and its supports, as well as the afterburner fuel injection struts (if these are not retracted), will affect the supersonic flow stream and these must therefore be designed with minimum stream shock losses as an objective.

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* An inlet closed rocket vacuum mode is feasible for ScramLACE provided vehicle supplied oxidizer (liquid oxygen, liquid air) is available. This mode is schematically indicated in the ScramLACE section of the present report.

SCOPE AND CONTENT OF THE REPORT

As stated, this report includes a separate section for each of the two (2) engine concepts described above. The original numerical coding assigned to these engines as candidates (Class 0 Phase, Ref. 1) is retained for continuity, the engine sections appearing here in numerical order.

The orientation of the engine data presented herein is toward direct user processing for broad and diversified study activities. Performance, weight, physical envelope characteristics, operating mode availability, and other information of this genre is arranged here in a manner intended to promote effective assimilation of composite engine data by the reader. For this reason, the documentation of interpretative results of the engine data, e.g. mission application studies, is left in the main body of the report (Ref. 3). Similarly, discussions bearing on the trade-off studies leading to selection of engine design parameters, such as primary rocket chamber pressure, also remain in the main report, since - per se - these may not be of immediate utility to a systems analyst striving to assess the applicability of composite engines to his particular mission requirement.

Therefore, as appropriate, reference should also be made to the main body of the Study's final report documentation (Ref. 3). There the bulk of the parametric analysis which, for example, explore the effect of the internal design variables, is provided. Also the Study's vehicle integration and mission performance work is represented in these volumes.

Each of the two engine sections to follow is divided into two parts: (1) Engine Description, Physical Characteristics, and Performance, and (2) Engine Sensitivity Analysis - Bases and Results.

In further detail, the topics included, in the order presented, are:

Engine Description, Physical Characteristics and Performance

1. Descriptive Text, Schematic, Operating Mode Block Diagrams
2. Detailed Conceptual Drawing (Includes Numerical Statement of Design Features)
3. Weight Statement
4. Operating Mode Schematic Diagrams
5. Propellant Flow Circuit Description
6. Vehicle Installation Description

7. Assumed Inlet Physical Characteristics and Pressure Recovery Schedule

8. Ejector mode (or supercharged ejector mode) specific impulse, thrust and airflow maps reflecting the effect of vehicle flight speed and altitude. These maps are backed up by computer-generated tabular data.

9.* Fan-ramjet mode specific impulse and thrust maps.

10. Ramjet (subsonic combustion) specific impulse and thrust maps, including the effect of inlet air precompression (flow field).

11.**SCRAMJET (supersonic combustion) specific impulse and thrust data, including the effect of inlet air precompression (flow field). This information is presented for three reference trajectories which follow the performance curves.

12.* Fan (ducted) operation specific impulse and thrust maps, reflecting the effect of varying degrees of plenum burning.

<u>Sensitivity Analysis - Bases and Results</u>

1. Reference Trajectories

2. Baseline Specific Impulse and Thrust (both net jet) Performance Values derived on the reference trajectories

3. Range and Limiting Values of Sensitivity Parameters, Performance and Weight

4. Perturbed Specific Impulse and Thrust - results for each sensitivity parameter.

Preceding the individual engine sections, and immediately following this section, a general reference section appears which includes:

1. Mach Number/Velocity Conversion Chart

2. Engine Station Nomenclature Diagram

3. General nomenclature and legends

4. List of references

* Engine No. 11 only
**Engine No. 22 only

SUMMARY - GENERAL REFERENCE DATA

The purpose of this section as noted in the introduction is to provide technical information and general background material applicable to the two (2) specific engine sections to follow. Each of the items to be provided in this general section will be briefly discussed below.

Mach Number versus Flight Velocity Conversion Chart - Although the basic engine performance information to be presented in this report is given generally on the basis of flight velocity (ft/sec, m/sec), much of the general information as well as the intermediate data is most effectively and conveniently stated in terms of Mach number. A conversion plot is provided to assist in approximate conversions of these two velocity terms. For more precise computations the use of appropriate tables, however, is recommended.

Engine Station Designation and Nomenclature - An installed engine schematic is presented reflecting a typical composite engine of the Class 2 series. The several aerothermodynamically significant geometric stations employed in the engine general description, as well as in the performance computations, are called out in this figure.

Standard Efficiencies - The following listed efficiencies have been used as baseline values for all engine performance computations:

Primary Rocket:
- Combustion, $\eta_c^* = 0.975$
- Nozzle, $\eta_n = 0.98$

Mixer:
- Mixing, $\eta_m = 0.80$

Afterburner or Combustor:
- Combustion, $\eta_c = 0.95$

Exit:
- Nozzle $\eta_n = 0.98$

Legends, Nomenclature, and References - Within the engine sections certain diagrammatic conventions have been adopted and these are reflected in both schematic and tabular form in this section of the report. Also a nomenclature sheet is provided for all symbolic characters employed either in the presentation of the engine information, or in the computations supporting the performance provided. Finally a list of references is given at the end of this section.

FIGURE 1 FLIGHT VELOCITY - MACH NUMBER

U. S. STANDARD ATMOSPHERE, 1962

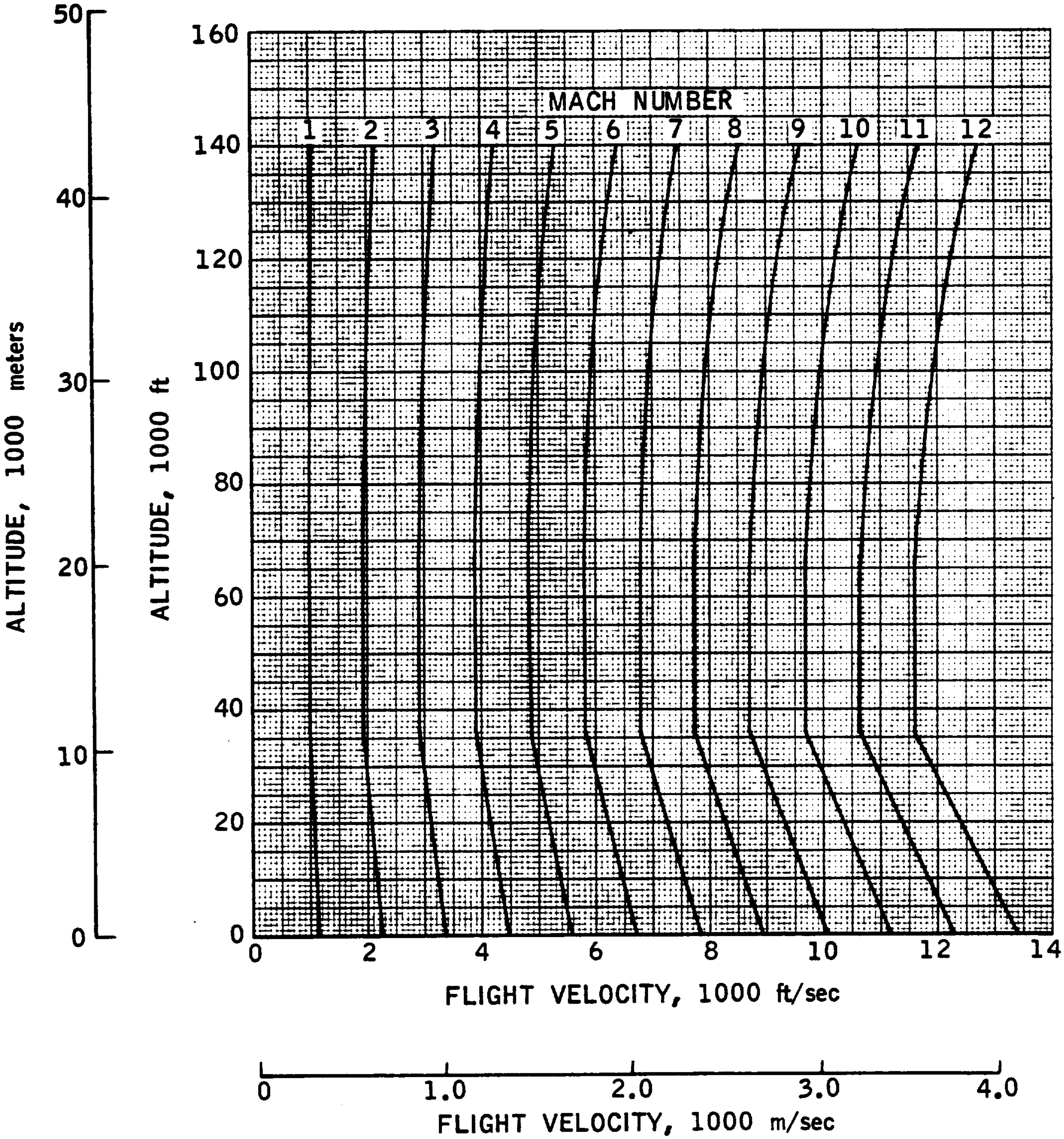
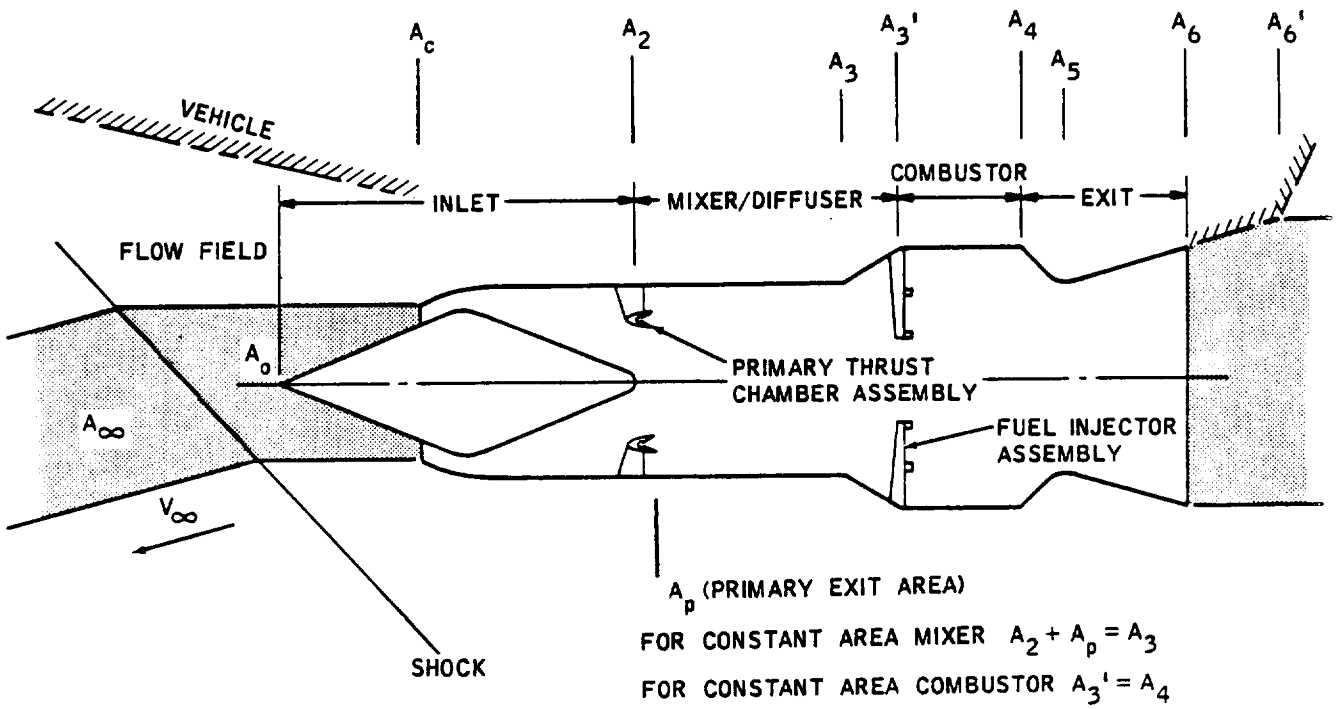


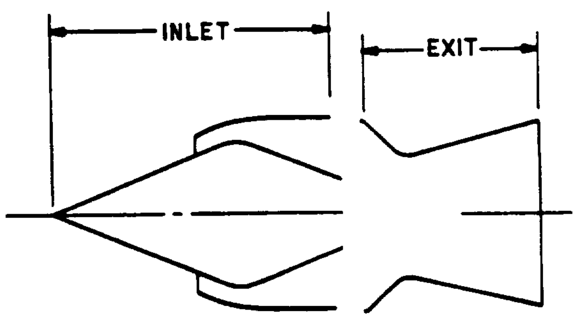
FIGURE 2 INSTALLED ENGINE STATION NOMENCLATURE



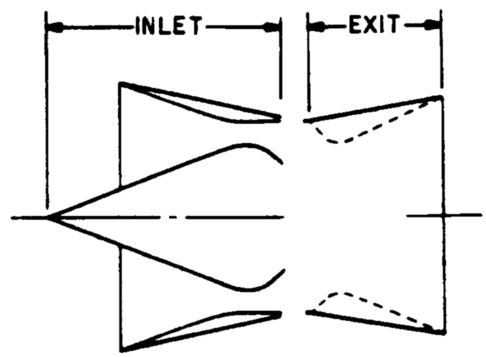
The basic flow processing situation in a representative composite engine is schematized in this chart, which also provides the station nomenclature used in the study. It will be note that both on the inlet and the exit portions of the aerothermodynamic processes the favorable utilization possibilities of the vehicle are assessed. The precompression of the induced air by the vehicle body (vehicle bow shock system) is fundamentally important in providing high engine thrust performance, particularly in the ramjet modes. At the same time, the possibility of expanding the exhaust flow on the vehicle aft body is of fundamental importance, critically so for the SCRAMJET mode.

LEGEND - ENGINE SCHEMATIC

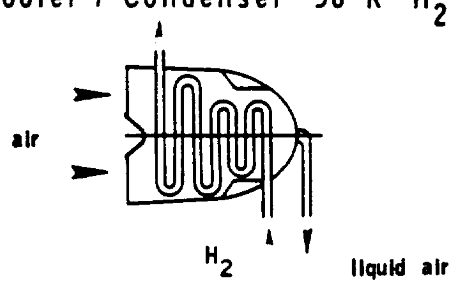
Inlet / Exit: Subsonic Combustion



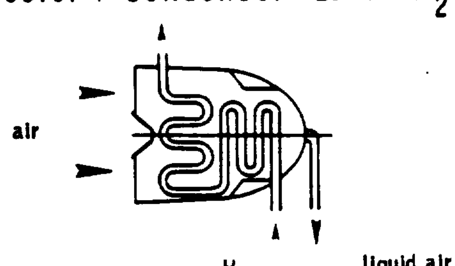
Inlet / Exit: Supersonic Combustion (Including Sub/Super Conversion)



Precooler / Condenser 36°R H_2



Precooler / Condenser 25°R H_2



LEGEND - ENGINE OPERATING MODE BLOCK DIAGRAM

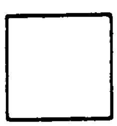
Letter Symbols (Within Blocks)

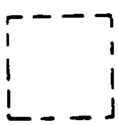
I	Inlet Subsystem	
HE	Heat Exchanger	
F	Fan Subsystem	
R	Rocket Subsystem	
MC	Mixer/Combustor	Mixer/Combustor/Exit Subsystem
MD	Mixer/Diffuser	Mixer/Combustor/Exit Subsystem
C	Combustor	Mixer/Combustor/Exit Subsystem
E	Exit	Mixer/Combustor/Exit Subsystem

Letter Symbols (Fluids)

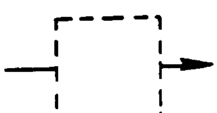
H	Hydrogen
O	Oxygen
A	Air
X	Exhaust

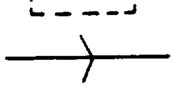
Graphical Symbols

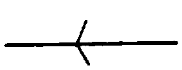

Functioning Unit

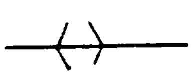

Non-functioning Unit

Fluid Flow Direction


Fluid Flow Through a Non-functioning Unit


Flow Mach Number >1


Flow Mach Number <1


Flow Mach Number is both below and above 1 at changing flight speed conditions

NOMENCLATURE

Nomenclature used in this report is given below. The tabulated computer printout information does not include subscripting as will be noted by the repetition of certain parameter symbols. Refer to Figure 2 for engine flow area station designations including the distinction made between A_∞ and A_o where a vehicle flow field is involved (where there is no flow field these are identical).

AB	-	Afterburner
A_4/A_3	-	Afterburner/Mixer Diffusion Ratio
A5	-	Engine nozzle throat area, ft^2
A6	-	Engine nozzle exit area, ft^2
A_6/A_5	-	Exit Nozzle Expansion Area Ratio
A_6/A_c	-	Exit to Capture Area Ratio (SCRAMJET)
AHX	-	Inlet capture area for heat exchanger air flow, ft^2
AO	-	Inlet capture area for secondary air flow, ft^2
AOT	-	Inlet capture area for total air flow, ft^2
BL	-	Baseline
C_F, CF	-	Thrust Coefficient based on inlet capture area
H2	-	Secondary air static enthalpy at mixer entrance, Btu/lb
HTO	-	Ambient Total Enthalpy, Btu/lb
I_{sp}, IS	-	Specific Impulse, lb_f/lb_m/sec (Net Jet)*
M_o, MO	-	Local Mach Number
M2	-	Mixer entrance Mach number
NS	-	"Normal Shock" inlet (Includes Normal Shock losses plus an assumed 90% diffuser efficiency.)
O/F	-	Oxidizer/fuel mass flow ratio
P2	-	Secondary air static pressure at mixer entrance, Btu/lb
P_c	-	Primary chamber pressure, psia
PR_f	-	Fan pressure ratio
P_{T_2}, PT2	-	Inlet recovered total pressure, psia
P_{T2}/P_{TO}	-	Inlet total pressure recovery
PTO	-	Ambient total pressure, psia

R	-	Rocket Mode
Ref	-	Reference
SLS	-	Sea Level, Static Conditions
SPC	-	Specific Fuel or propellant consumption, $lb_m/hr\text{-}lb_f$
T	-	Thrust, lb_f (Net Jet)*
V6	-	Exit velocity, ft/sec
V_O, VO	-	Local velocity, ft/sec
WFT	-	Total fuel or propellant flow rate, lb_m/sec
WHX	-	Heat exchanger air flow rate, lb_m/sec
W_P, WP	-	Primary flow rate, lb_m/sec
W_S/W_P, WSWP	-	Secondary/primary flow ratio
W_S, WS	-	Secondary (WS + WHX), lb_m/sec
WT	-	Total air flow
δ	-	Two dimensional wedge half angle, deg
η_c	-	Combustion efficiency based on enthalpy rise
η_{c^*}	-	Characteristic velocity efficiency based on velocity, or thrust
η_{KE}	-	Inlet kinetic energy process efficiency
η_M	-	Mixing Efficiency based on static pressure rise
η_N	-	Nozzle efficiency based on stream thrust
ϕ, ϕ_{AB}	-	Combustor equivalence ratio
ϕ_{cond}	-	Condenser equivalence ratio
ϕ_{HX}	-	Heat exchanger equivalence ratio
ϕ_P, PHP	-	Primary rocket equivalence ratio
ϕ_{prec}	-	Precooler equivalence ratio
ϕ_{sec}, PHS	-	Secondary equivalence ratio

* Net jet thrust and specific impulse includes air induction inlet momentum penalty, but does not include external drag such as cowl, induced, friction, or spillage drag

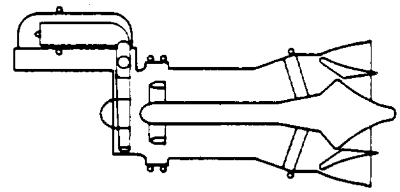
LIST OF REFERENCES

1. "Class O Engine Fact Sheets (Thirty-six Engines)", Contract NAS7-377, Marquardt Report 25,194, Volumes 4 & 5, Sept.1966. CONFIDENTIAL - Title Unclassified.

2. "Class 1 Engine Information (Twelve Engines)", Contract NAS7-377, Marquardt Report 25,194, Sept. 1966. CONFIDENTIAL - Title Unclassified.

3. "A Study of Composite Propulsion System for Advanced Launch Vehicle Applications (Main Technical Report)", Contract NAS7-377, Marquardt Report 25,194, Volumes 2 & 3, Sept. 1966. CONFIDENTIAL - Title Unclassified.

SUPERCHARGED EJECTOR RAMJET, NO. 11



The Supercharged Ejector Ramjet (Engine No. 11, Class 2 Study Phase) is a 215,000 lbf thrust (sea level, static) engine with Mach 8 flight speed capability. The propellants are liquid hydrogen and liquid oxygen and the engine normally operates in four progressive modes: (1) supercharged ejector mode, (2) fan ramjet mode, (3) subsonic combustion ramjet mode and (4) fan operation mode.

As displayed in this section, the engine has an overall length of 371 in. (9.4 meters), an overall diameter of 142.5 in. (3.62 meters) and a height maximum of 165 in. (4.19 meters). The uninstalled engine weight is 11,940 lbm, yielding a sea level thrust-to-weight ratio of 18.0.

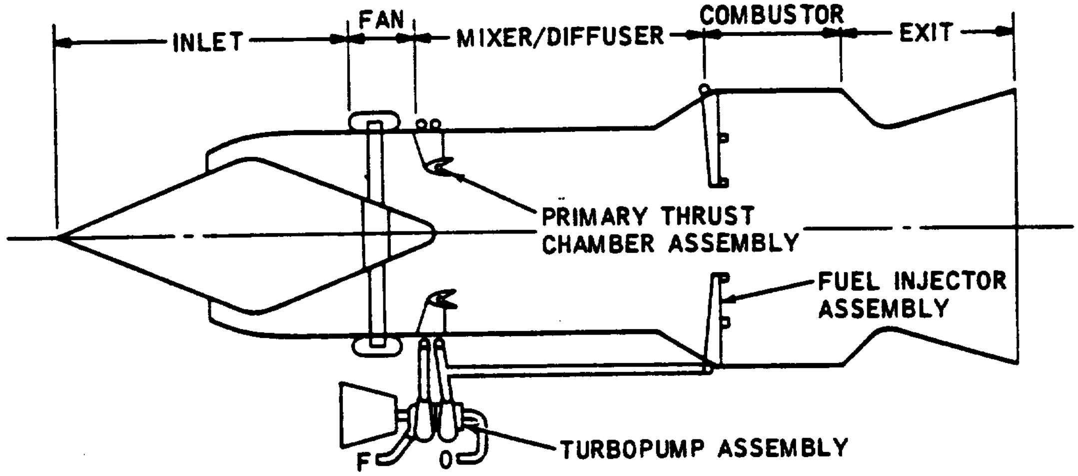
The basic design specifiers for the engine are as follows: Design mass flow ratio 3.0 to 1, primary chamber pressure 1500 psia, fan pressure ratio 1.3, maximum internal pressure 150 psia.

The engine features a single stage retractable tip-turbine fan powered by a twin airbreathing gas generator installation. The fan bypass ratio is 10 to 1. The primary rocket is a regeneratively cooled annular bell configuration featuring a single toroidal combustion chamber fed by separate hydrogen and oxygen pumps. The turbopump drive operates on the gas generator cycle using self-pumped propellants. A third hydrogen pump provides fuel to the afterburner, during the supercharged ejector mode, and thereafter feeds the ramjet combustor during high speed operations. The afterburner fuel pump is also powered by a bi-propellant gas generator utilizing self-pumped fuel and pressurized liquid oxygen provided from the vehicle.

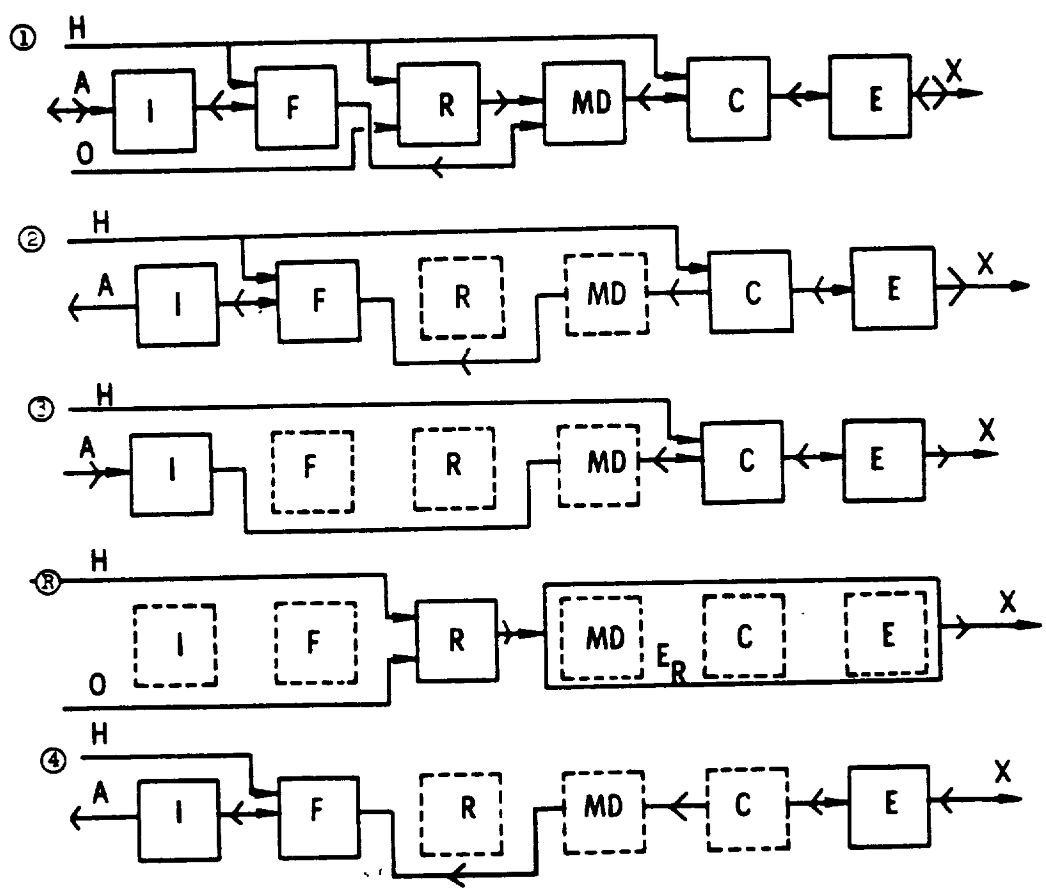
The basic engine structural components (mixer, diffuser, afterburner and exit nozzle) consist of regeneratively cooled assemblies employing a ring-stiffened Rene' 41 wire-wrapped, brazed regenerative Hastelloy X tube bundle construction. Within the mixer is an elongated centerbody which structurally connects a fixed aft plug with the forward thrust ring. The center body and plug assembly is supported by a multiplicity of radial low drag fuel injector struts commencing at the afterburner station. Variable exit geometry is accomplished by means of a translating ring operating continuously to provide two coaxial flow expansion compartments between the outer exit bell and the fixed plug. This dual throat design provides a minimum weight, single moving part design and provides high nozzle performance.

The engine was sized for a 1 million lbm gross weight, horizontal takeoff, two-stage launch vehicle. The engine was located in a complement of five (5) along the bottom side of a high fineness ratio, low drag, lifting body boost stage. Air induction considerations for this installation consisted of a moving ramp, two-dimensional variable inlet with mixed external and internal compression. The inlet capture plane was located to make full use of body flow-field affects at speeds in excess of Mach 3. Exit gas expansion is considered to take place solely within the exit bell of the engine.

Engine Operating Schematic



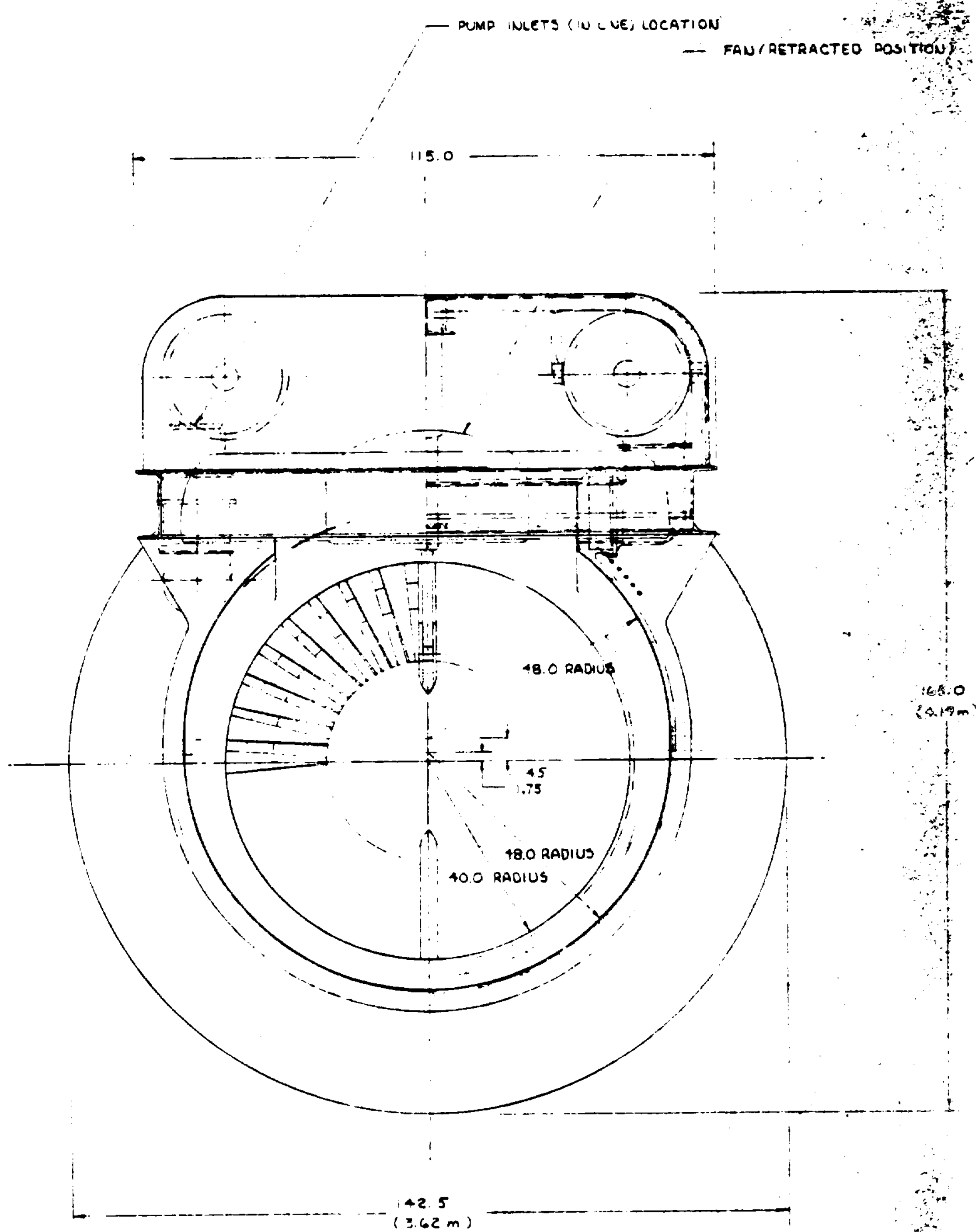
Engine Operating Mode Block Diagrams *



*Note: Mode numerical coding is given on Page 18, first paragraph, "R" indicates optional all-rocket mode.

[redacted]

[redacted]

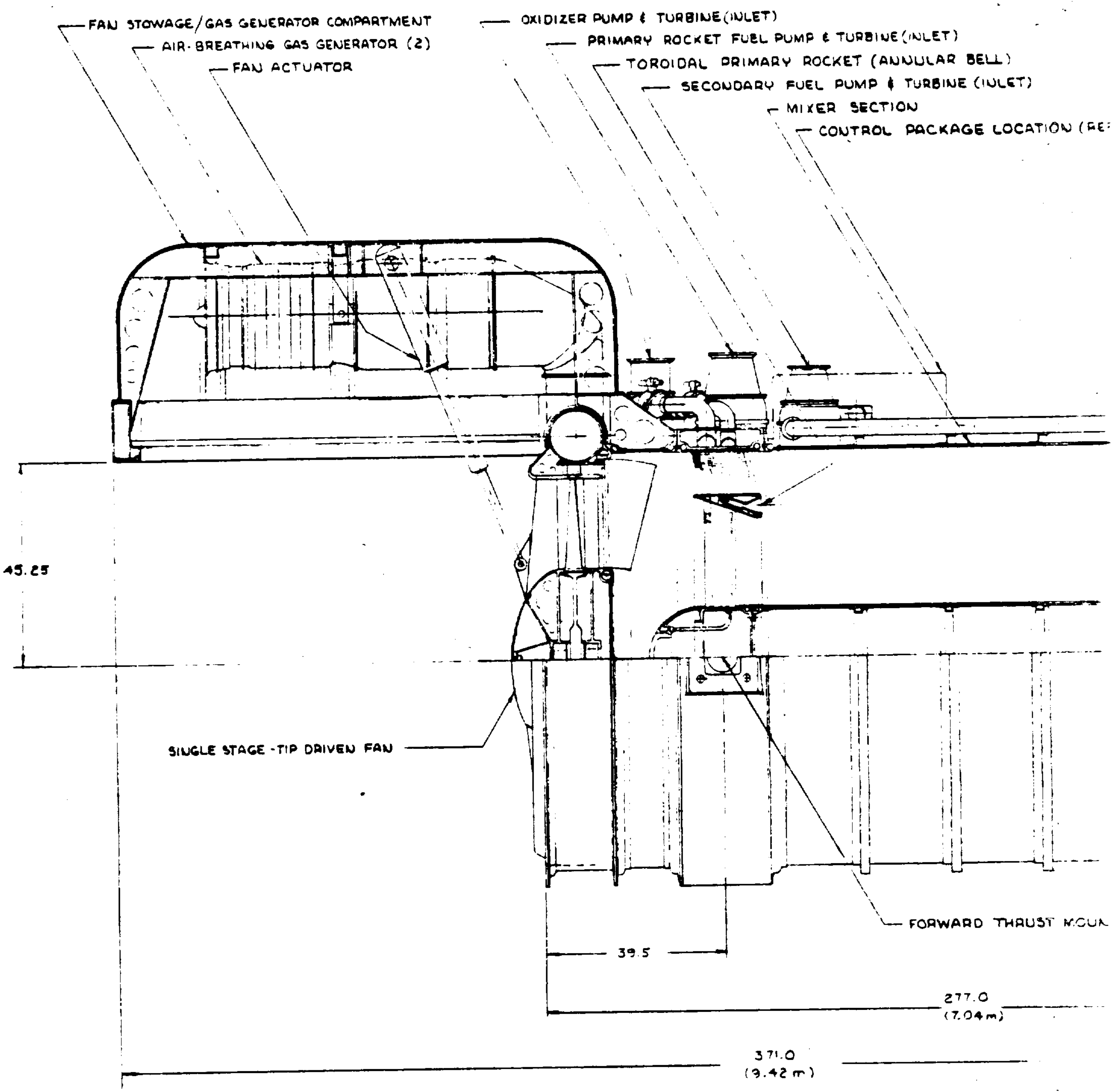


[redacted]

[redacted]

90-1

[redacted]



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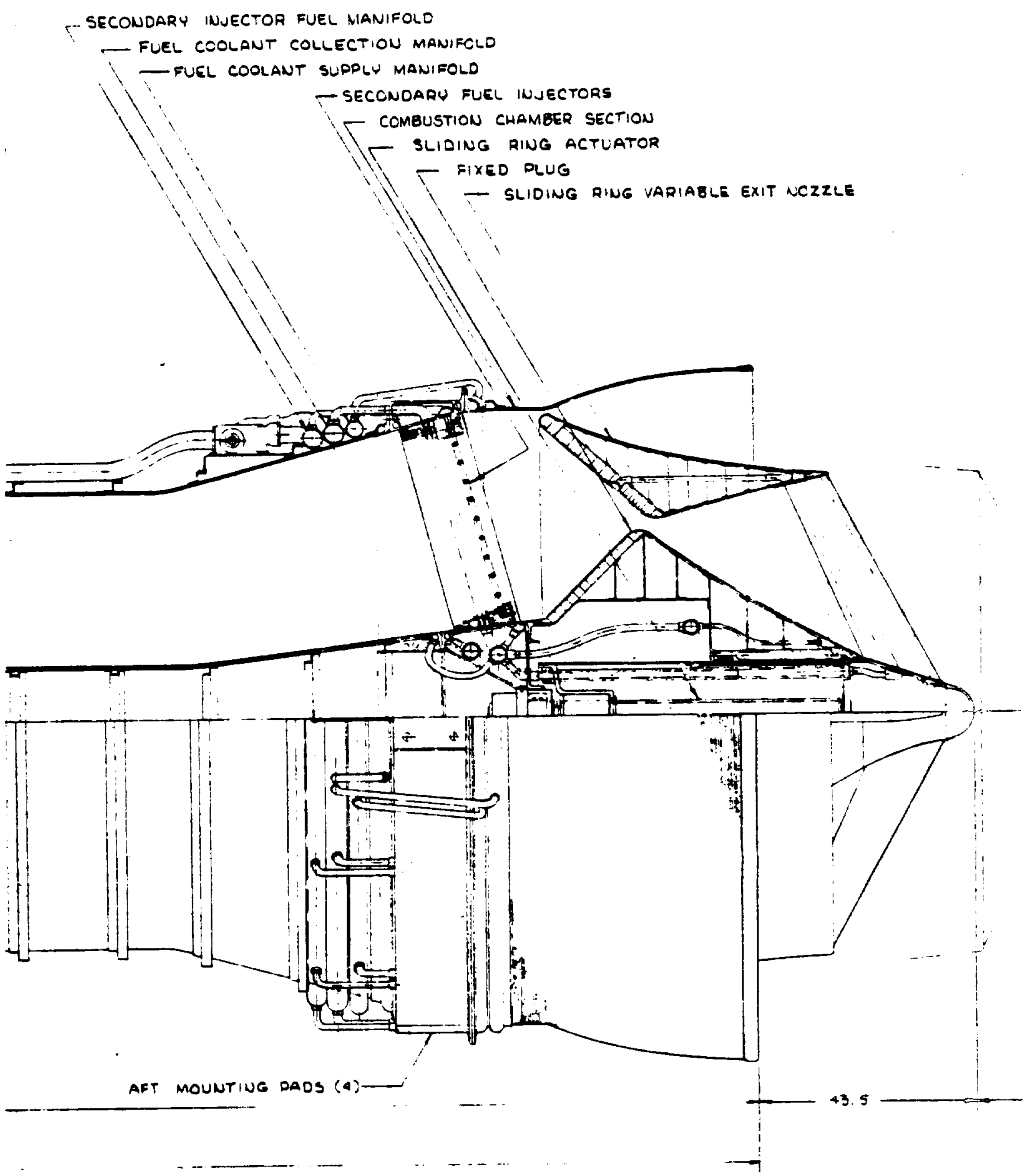
[redacted]



[redacted]

[redacted]

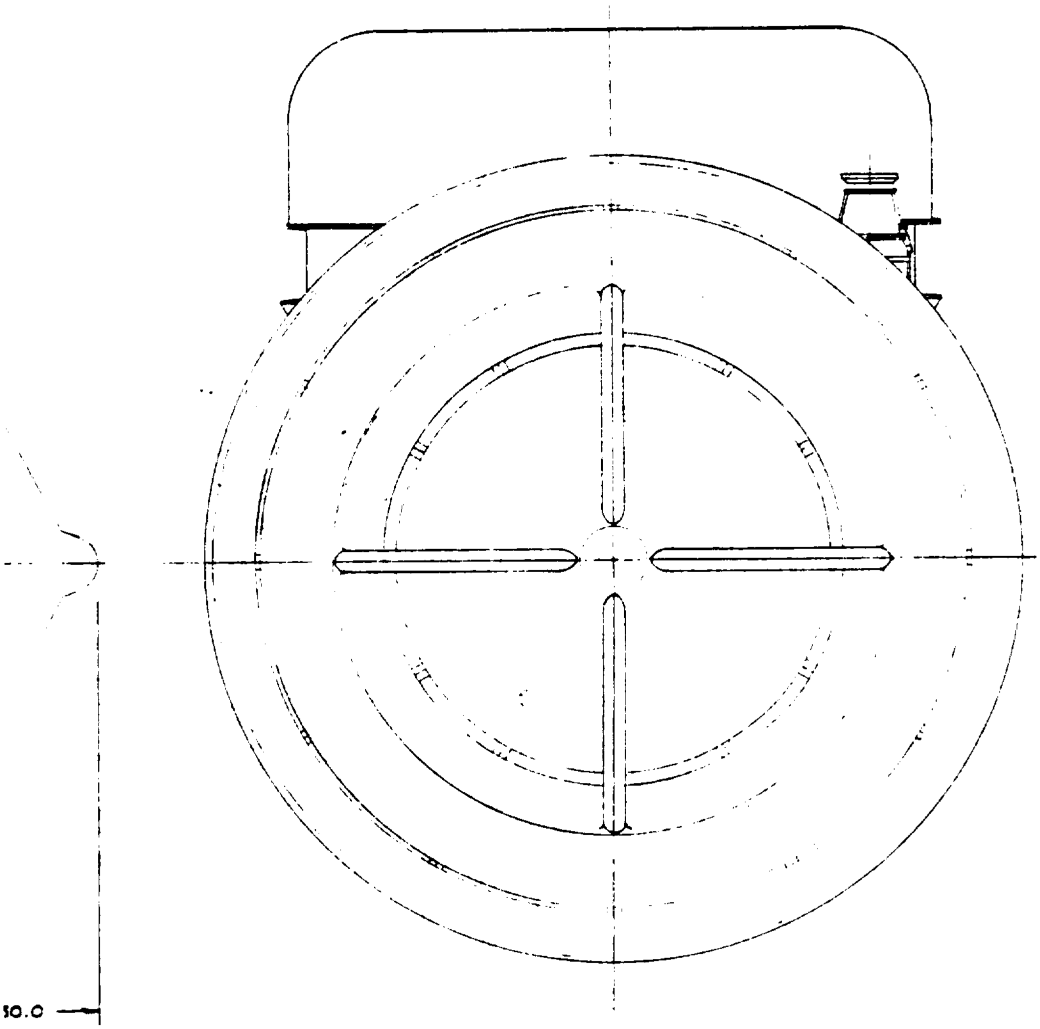
DESIGN CHARACTERISTICS
1. MACH 8 FLIGHT SPEED CAPABILITY
2. THRUST, SEA LEVEL STATIC : 215,000 LBS
3. PROPELLANTS: HYDROGEN-OXYGEN

DESIGN PARAMETERS
1. SECONDARY/PRIMARY MASS FLOW RATIO (S/P): 3.0
2. PRIMARY ROCKET CHAMBER PRESSURE : 1500 PSIA
3. PRIMARY ROCKET O/F RATIO (O/H) 7.94 : 1
4. MAXIMUM INTERNAL PRESSURE, DESIGN 50 PSIA
5. FAN PRESSURE RATIO, DESIGN 1.3 : 1
6. FAN / AIR BREATHING GAS GENERATOR BY-PASS RATIO 10:1
7. SECONDARY AIR EQUIVALENCE RATIO NOMINAL 1.0

ENGINE FLOW AREAS
1. MIXER A_3 = 43.49 SQ. FT.
2. COMBUSTOR/AFTERBURNER A_4 = 76.24 SQ. FT.
3. NOZZLE THROAT, A_5
MAX. = 68.5 SQ. FT.
MIN. = 7.0 SQ. FT.
4. NOZZLE EXIT, A_6 = 107.0 SQ. FT.
5. AFTERBURNER/MIXER DIFFUSION RATIO A_4/A_3 = 1.75 : 1

OPERATION MODES
1. SUPERCHARGED EJECTOR, MACH 0-2.5
2. FAN RAMJET, MACH 0.5-2.5
3. RAMJET, MACH 1-8
4. FAN OPERATION, MACH 0-0.9

[redacted]



1. ALL DIMENSIONS IN INCHES UNLESS OTHERWISE STATED
Note:

[redacted]

DRAWN HAMMILL 3/21/66	Marquardt
CHECKED E. JONES 3/29/66	SUPERCHARGED EJECTOR RAMJET ENGINE NO. 11 NAS 7-377 CLASS 2 STUDY PHASE
APPROVED E. SCHEER 4-5-66	66845 · R · X 9056
APPROVED	SCALE 1/10 · SHEET 1 OF 1

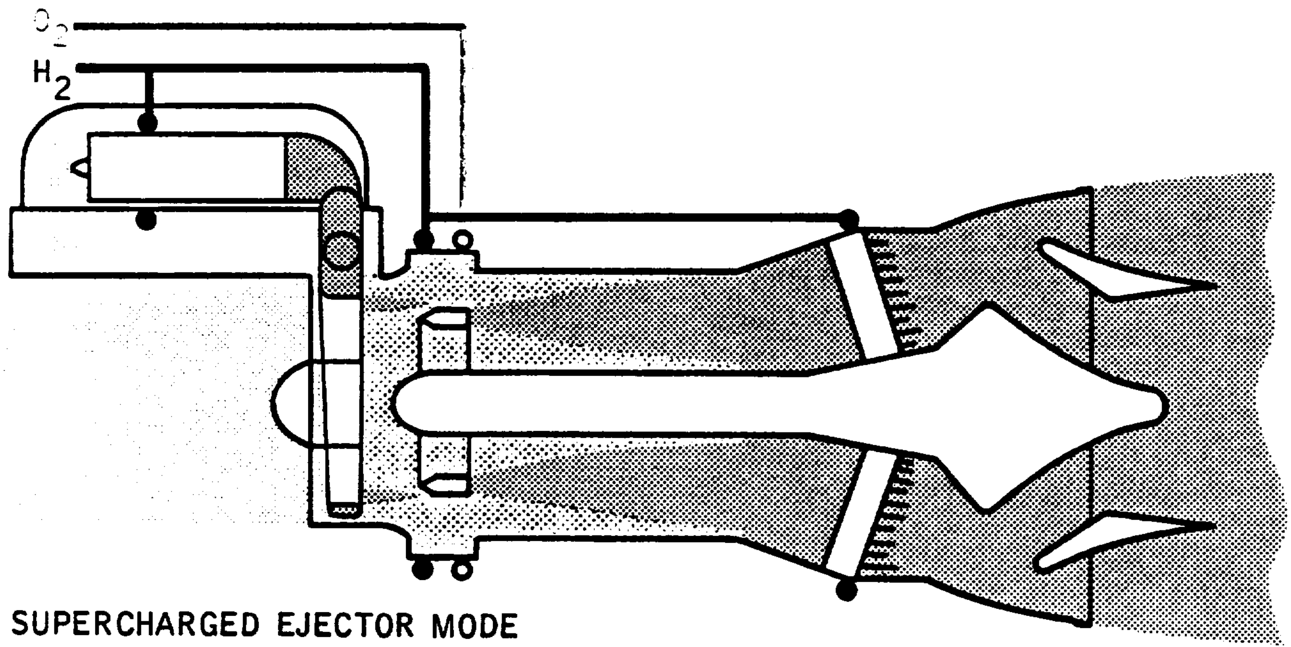
20-4

WEIGHT STATEMENT - ENGINE NO. 11

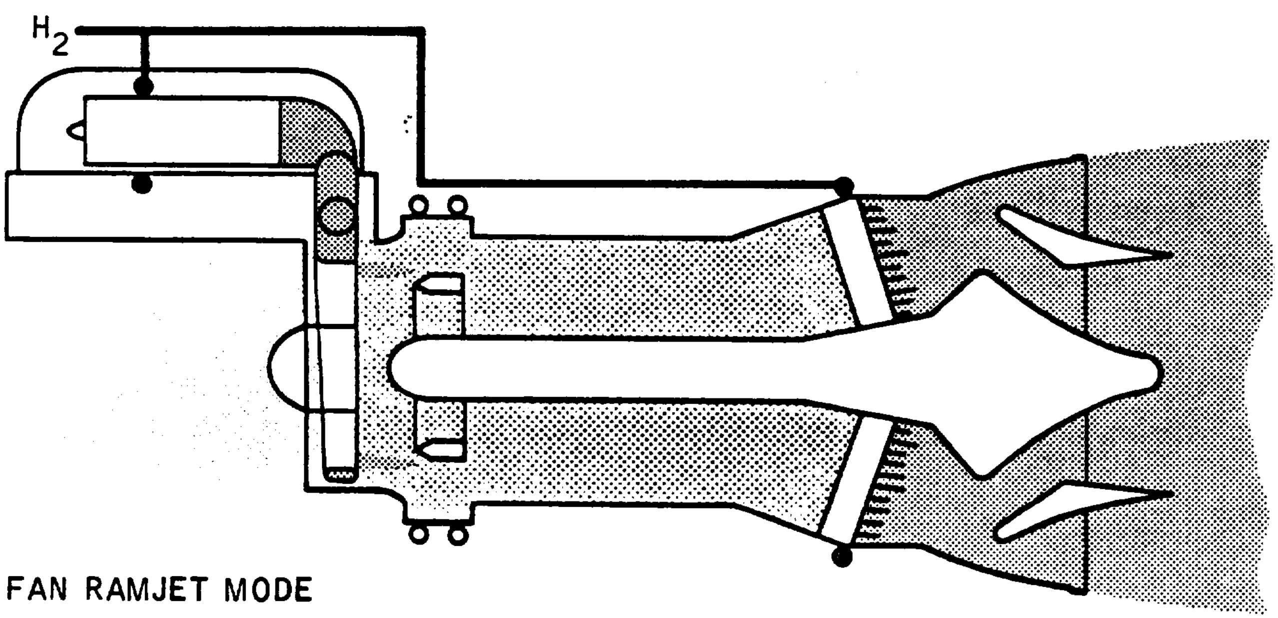
Fan Subsystem		4169 lbm
Fan Assembly	1258	(34.9%)
Gas Generators	1120	
Frame and Trunnion Unit	730	
Compartment Structure	360	
Cover	210	
Actuator	115	
Transition Section	306	
Miscellaneous (5%)	70	
Primary Rocket Subsystem		2028
Rocket Chamber Assembly	444	(17.0%)
Support Structure	927	
Turbopumps	316	
Gas Generator	127	
Ducting and Valves	88	
Starting System	126	
Mixer/Diffuser/Afterburner		2992
Mixer	1057	(25.1%)
Diffuser	540	
Fuel Injection Unit	635	
Combustor	315	
Forward Centerbody	300	
Turbopump and Miscellaneous	145	
Exit Nozzle Subsystem		2446
Exit Bell	523	(20.5%)
Translating Ring Assembly	973	
Fixed Plug	734	
Actuator Unit	100	
Miscellaneous	116	
Controls, Lines		305
Control Assemblies	80	(2.5%)
Valves and Lines	225	
Total Weight, Dry (Thrust = 215,000 lbf)		11,940 lbm (5416 kg)
Thrust/Weight, Uninstalled		18.0

SUPERCHARGED EJECTOR RAMJET (ENGINE NO. 11)

PROGRESSIVE OPERATING MODES
(PUMPING, COOLING AND CONTROL CIRCUITS NOT SHOWN)



SUPERCHARGED EJECTOR MODE

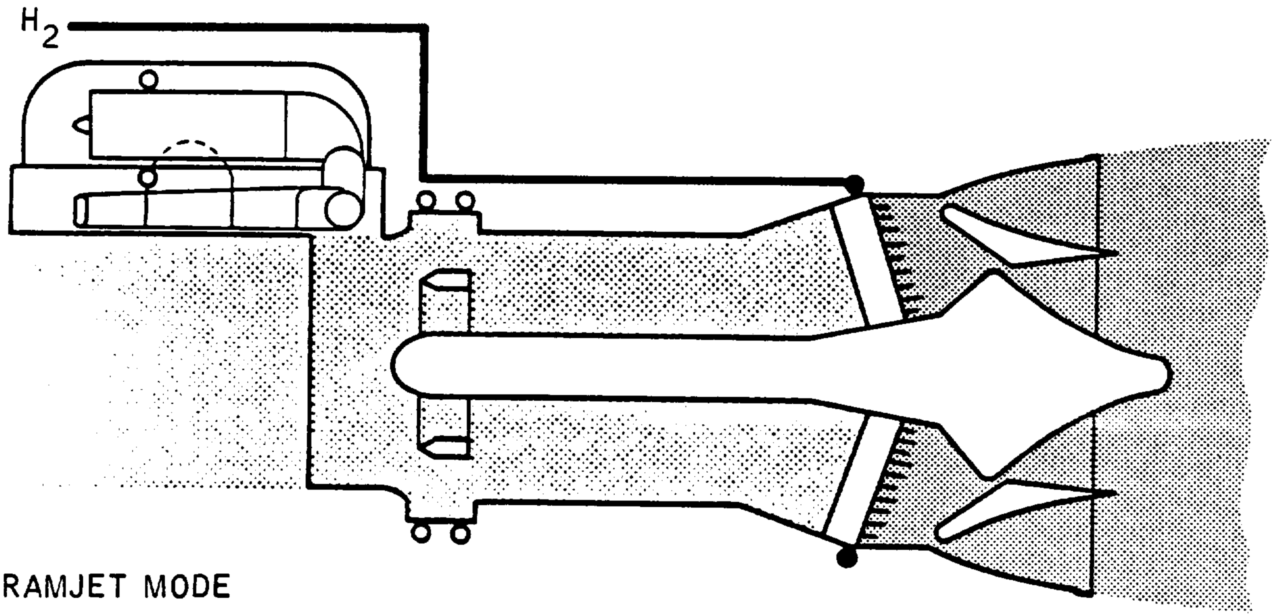


FAN RAMJET MODE

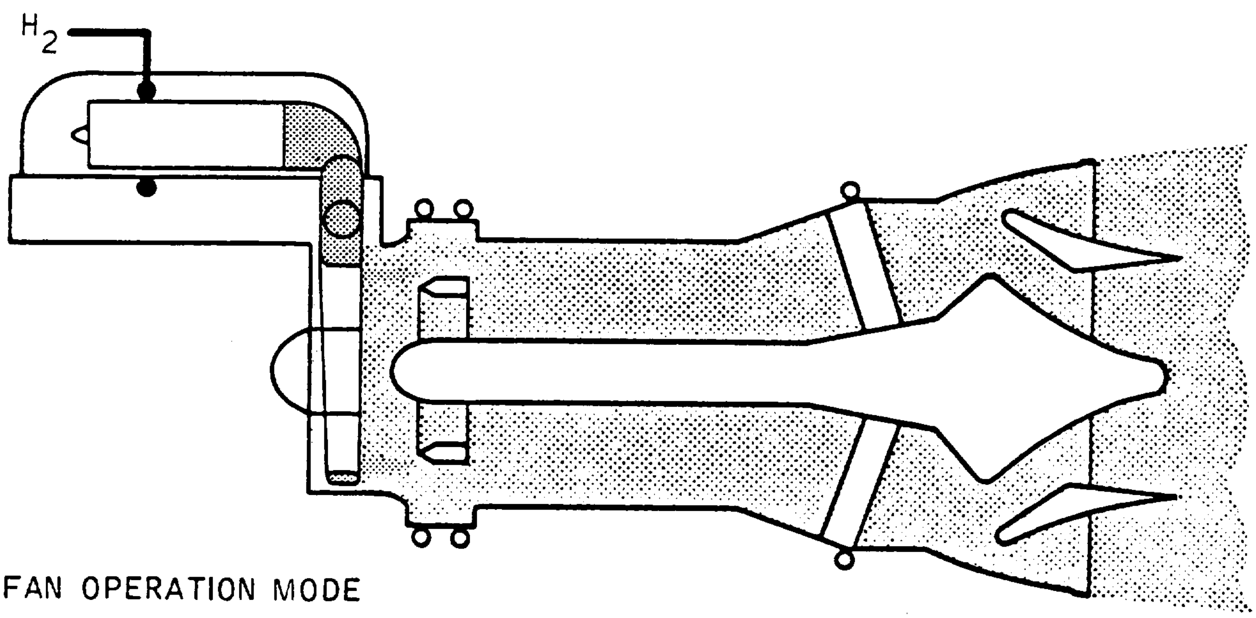
R-22,137

SUPERCHARGED EJECTOR RAMJET (ENGINE NO. 11)

PROGRESSIVE OPERATING MODES
(PUMPING, COOLING AND CONTROL CIRCUITS NOT SHOWN)



RAMJET MODE



FAN OPERATION MODE

BASIC PROPELLANT CIRCUIT
SERJ, ENGINE NO. 11

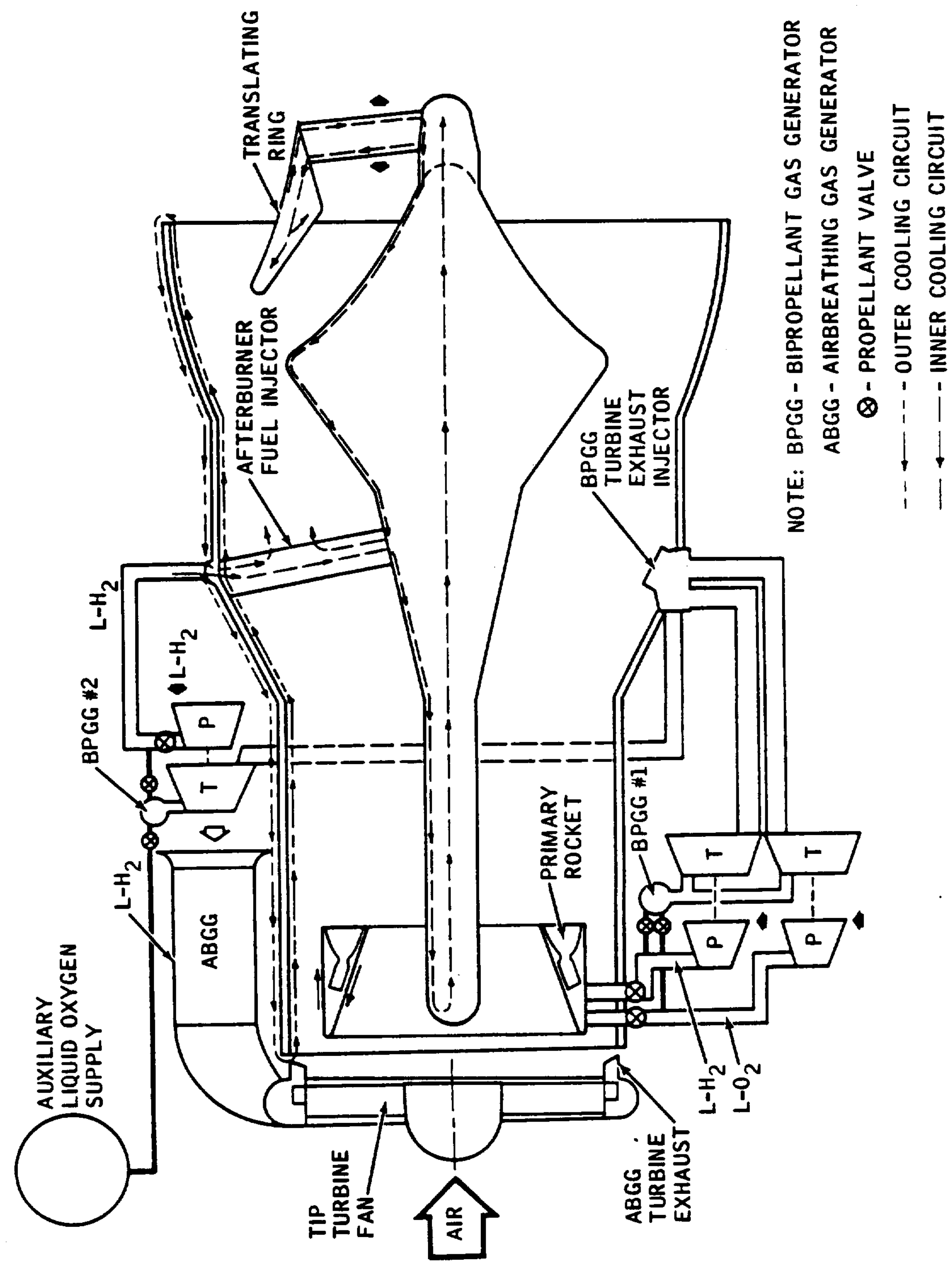
The propellant circuits for Engine No. 11 including the pumping, cooling and primary control elements are displayed on the facing figure. The engine is supplied hydrogen and oxygen as shown. The airbreathing gas generator, which is aerodynamically coupled to the tip turbine single stage fan, receives fuel and is controlled for maximum specific horsepower output.

The three pump units are directly shafted units requiring no gearing. One gas generator, operating on tapped propellants, is utilized to drive the primary rocket fuel and oxidizer pump (bottom of figure) to supply the combustion chamber operating at 1500 psia. A second bipropellant gas generator drives the afterburner fuel pump which provides hydrogen at an output pressure of 1000 psia. For the ramjet mode it is required that auxiliary stored oxidizer be provided to the turbopump gas generator since oxygen itself is not being pumped in this mode. The primary rockets are fed through main propellant valves operating in either open or closed positions. Starting of the primary rocket is accomplished by turbine blow down from a separate high pressure gaseous hydrogen supply (not shown). The turbopump exhaust products, being considerably fuel rich, are conducted into the afterburner of the engine where the excess fuel is combusted with the induced air. This minimizes the turbopump drive penalty during the ejector mode. Likewise, the ramjet pump turbine exhaust is injected into the ramjet combustor. The turbine is therefore designed for back pressures commensurate with sonic exhaust flow at the full combustor pressure of 150 psia to preclude back pressure coupling effects.

The coolant passages consist of two parallel flow circuits to the outer jacket and to the inner centerbody/plug/nozzle assembly. The outer engine wall is cooled in two passes first forward and then aft in order to cool the exit nozzle with warmed hydrogen. The inner cooling circuit progressively cools the forward centerbody, translating ring and fixed plug. All coolant flow is injected into the afterburner via the self-cooled fuel injection struts. Also, the primary rocket external structure is cooled by regenerative structure during the high speed ramjet mode. During fan only operation, with little or no plenum burning the engine is essentially uncooled. For full stoichiometric afterburning (fan ramjet mode), regenerative cooling of the aft section of the engine is required.

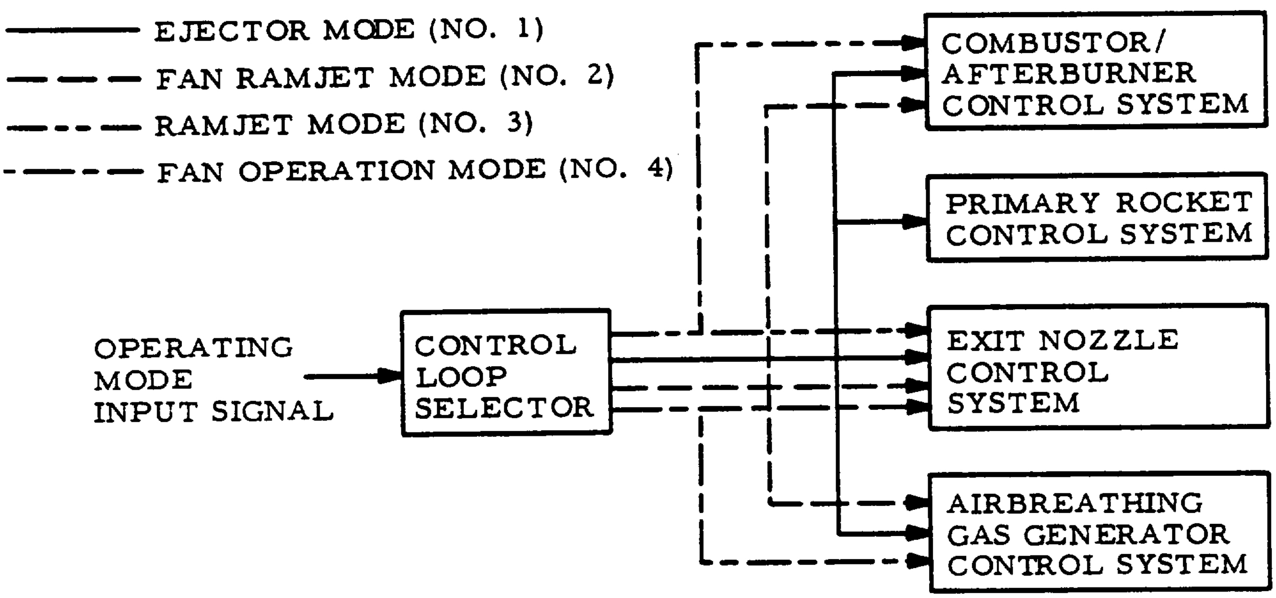
Eng. No. 11

ENGINE NO. 11 - BASIC PROPELLANT SCHEMATIC



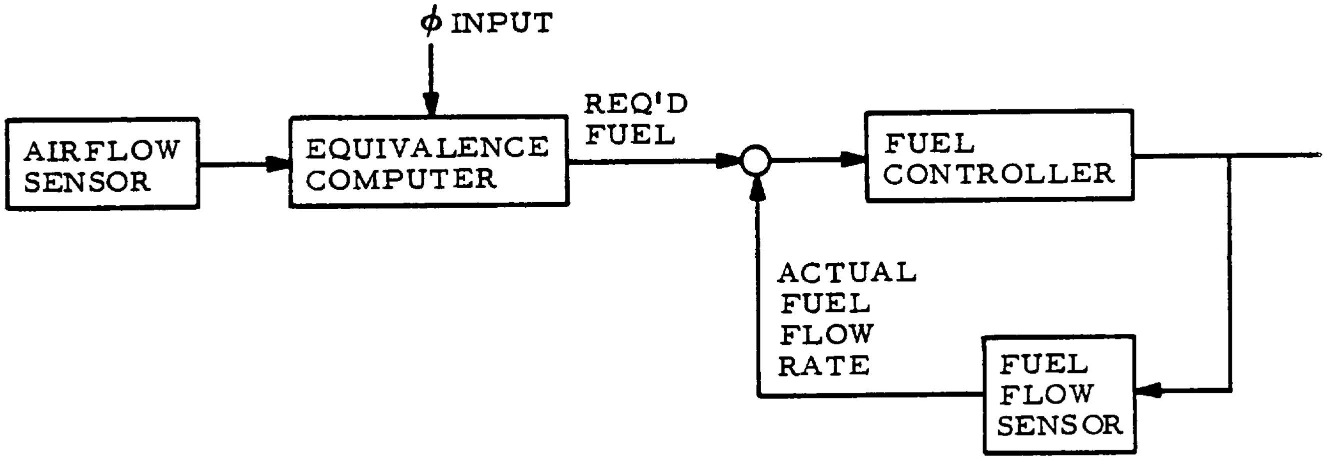
OPERATING MODE CONTROL SYSTEM

(BLOCK DIAGRAM)



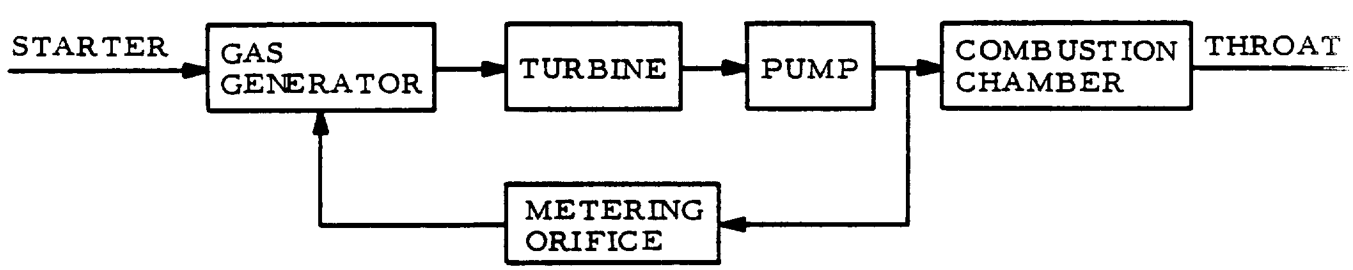
Engine control is based on manual and/or automatic selection of operating modes via four active control loops as will be described. The fan subsystem is controlled to operate at design rpm with protection of both the fan tip-turbine and the basic gas generator from turbine over-temperature. Retraction of the fan is effected at mode shift from the fan ramjet to subsonic combustion ramjet mode. The primary rocket is scheduled (pre-orificed) to operate at design chamber pressure and design oxidizer-to-fuel ratio (8.0 to 1). The afterburner/combustor controller is designed for operation at an equivalence ratio of 1, providing maximum thrust consistent with good performance. The variable exit nozzle is controlled initially to provide a maximization of the product of fan pressure ratio and air mass flow (approximately). Once supersonic flight is reached the variable exit is translated to locate the inlet nozzle shock at the throat of the inlet. The exit also operates in an override loop to limit combustor pressure or inlet diffuser pressure to the maximum design condition of 150 psia.

COMBUSTOR/AFTERBURNER FUEL CONTROL SYSTEM



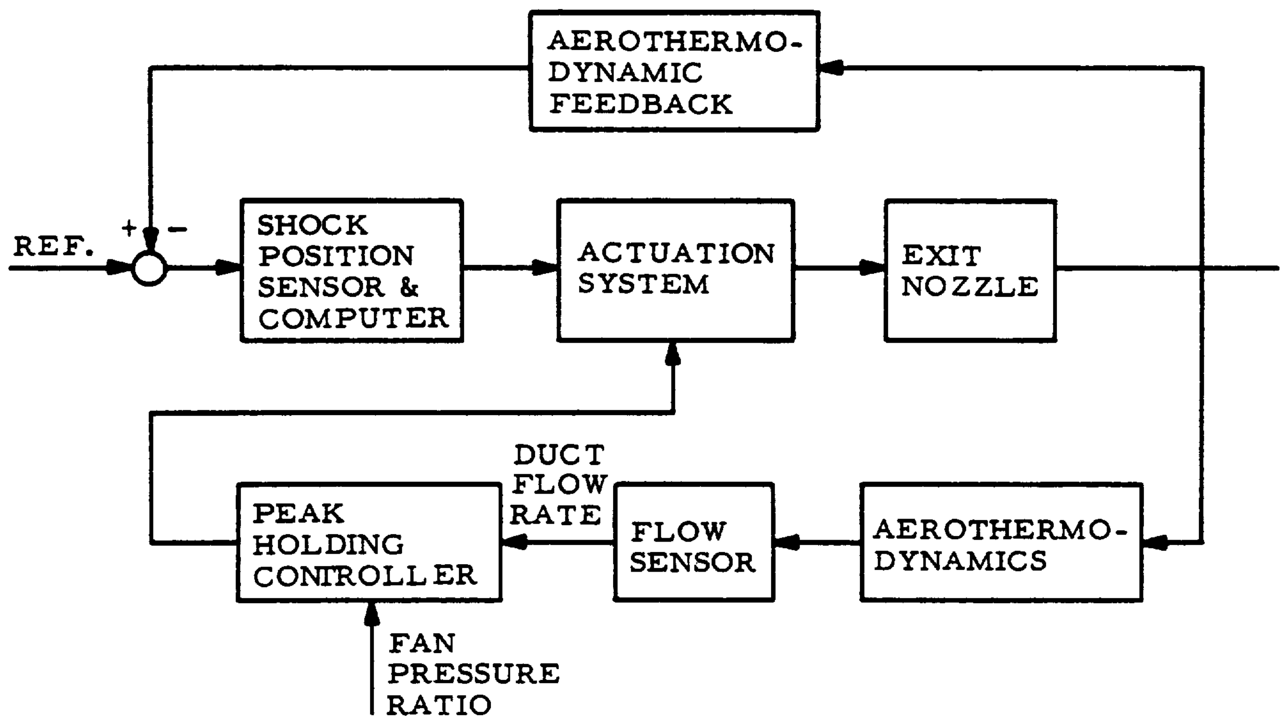
The combustor/afterburner fuel control system is a closed loop control system which senses the air flow rate through the engine and modulates the fuel flow rate to maintain a required fuel air ratio (ϕ). A signal proportional to air flow is applied at the equivalence computer which generates a command for the required fuel flow rate. This signal is compared against a fuel flow rate feedback signal generating an error signal which is applied at the fuel controller. The fuel controller modulates the fuel flow to null the error.

ROCKET FEED CONTROL SYSTEM



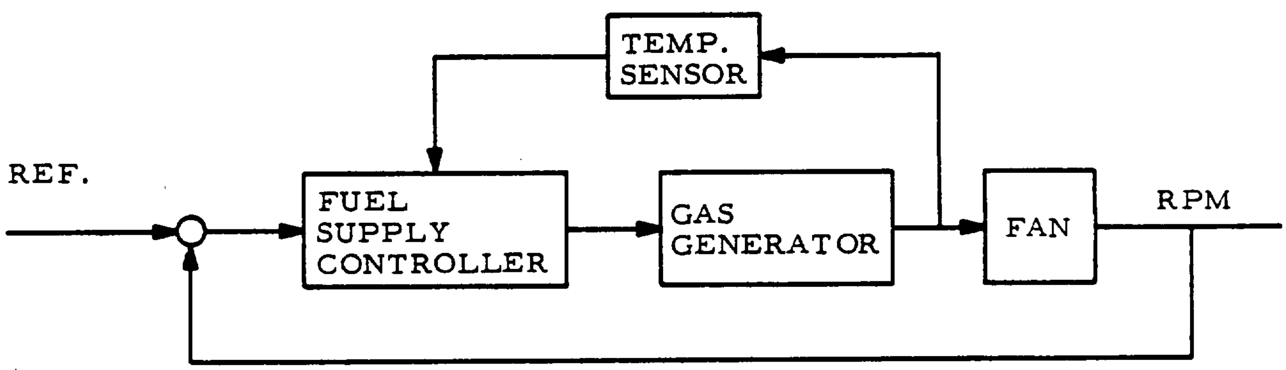
The rocket feed control system is a fixed point control system. A positive feedback from the pump which is controlled by a metering orifice is supplied to the gas generator to drive the turbine and pump assembly until the available power is equal to the required power which is the design condition (full chamber pressure). An external power source (gas blowdown) is introduced to start the operation of the system.

EXIT NOZZLE CONTROL SYSTEM



The exit nozzle control system performs two functions, i.e., positions the inlet shock at its optimum location and maximizes the combination of fan pressure ratio and duct flow rate by modulating the throat area of the exit nozzle. A pressure signal indicative of the position of the inlet normal shock is compared against an actual feedback signal generating an error which is applied at the actuation system to null the error. The actuation system receives another signal from the peak holding controller to maximize the combination of duct flow and fan pressure ratio. The actuation system will be designed with the capabilities of selecting the correct signal in the event there is a conflict between the two commands.

AIRBREATHING GAS GENERATOR CONTROL SYSTEM



The airbreathing gas generator control system which is a closed loop control system, maintains the fan speed (RPM) at a selected reference speed by throttling the fuel rate to the airbreathing gas generator. The reference speed is compared against the actual speed (feedback), generating an error which is fed to the fuel supply controller to modulate fuel flow to the gas generator. This, in turn, controls the fan speed until the error is nulled. A temperature override loop is included to limit the temperature of products of combustion from the gas generator and protect the fan tip-turbine.

VEHICLE DESIGN - SERJ, ENGINE NO. 11

This figure shows the final Class 2 vehicle design utilizing supercharged Ejector Ramjet engines. This 1.0 million pound gross weight lifting body vehicle was determined to be substantially superior in performance to the other vehicle types considered.

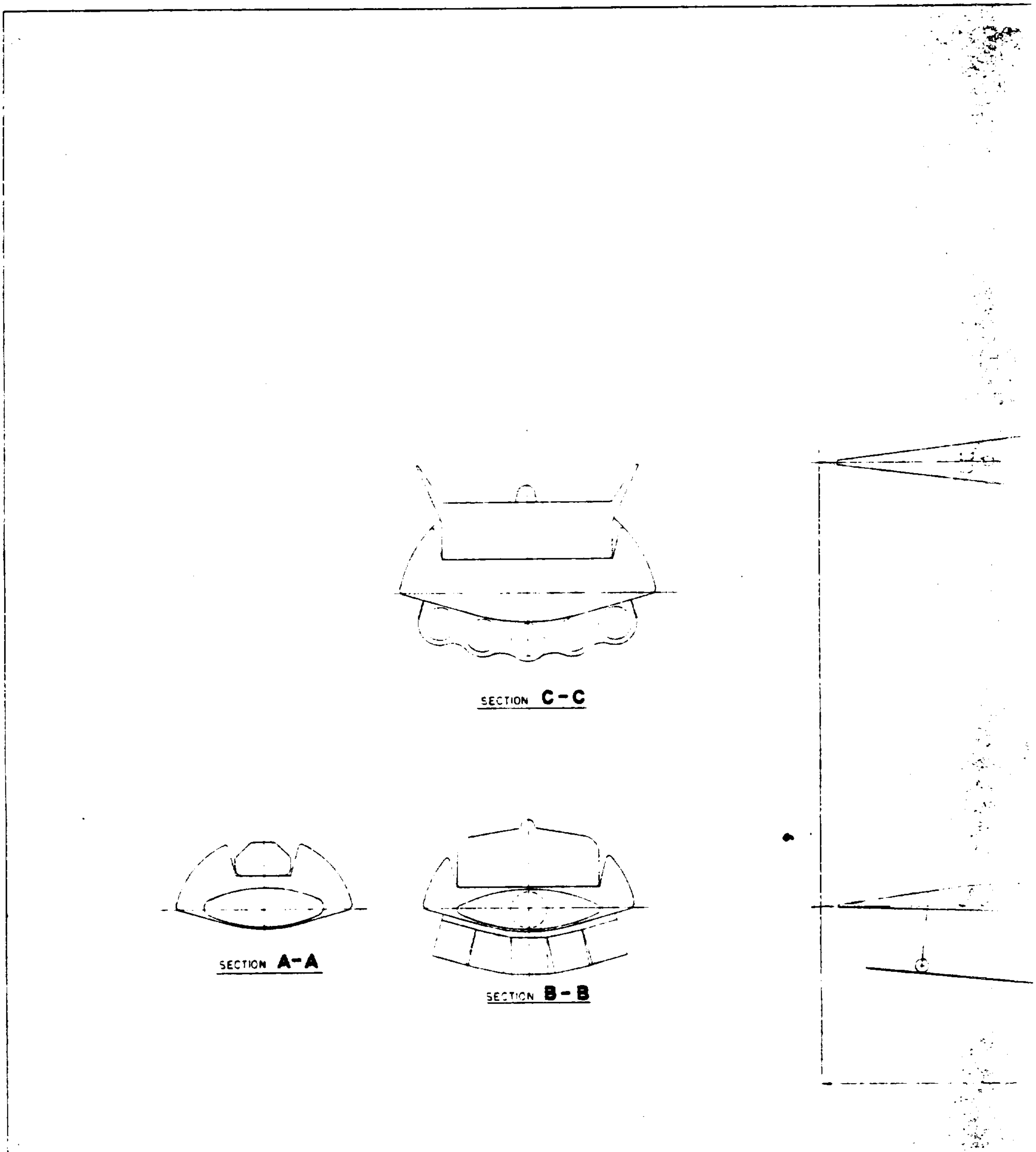
The lifting body shown features high slenderness ratio, elimination of the second stage base drag through submergence, and attainment of stabilizing surface at low unit weight. For the SERJ installation the aft vehicle extension contains no propellants but provides for increased slenderness ratio. This SERJ Mach 8 vehicle has a complement of five 215,000-lb SLS thrust engines (1.075 T/W), with a capture area of 350 ft^2, integrated beneath the fuselage. The second-stage gross weight is 445,054 pounds for Mach 8 first stage cut-off conditions.

The lifting-body configuration employs a modified conical fuselage where the forebody is a blunted cone with a depth-to-width ratio of 0.4 at any station. Maximum cross section of the fuselage is at 73 percent of the body length, as measured from the virtual nose (apex). The fuselage nose radius is one foot, and the body planform area is 13,612 ft^2.

The horizontal stabilizer has a leading edge sweep of 65 degrees, and an area of 2612 ft^2. The airfoil section is double wedge, with a two-inch leading edge radius. The movable horizontal control surfaces comprise 2000 ft^2. The horizontal control surface rotates against the vertical stabilizer with forward extending dorsal fins, to alleviate the thermal problem associated with the sharp edges of the control surface under high-speed deflected conditions.

The twin vertical stabilizers have a total exposed area of 1200 ft^2, with a leading edge radius of two inches. No toe-in is provided for the verticals, rather, a concept of utilizing small outward rudder deflections to load the surfaces during hypersonic operation where the control surface lift curve slope is zero at zero deflection is proposed, in order to maintain minimum vehicle drag. All panel surfaces have a thickness ratio of 5 percent.

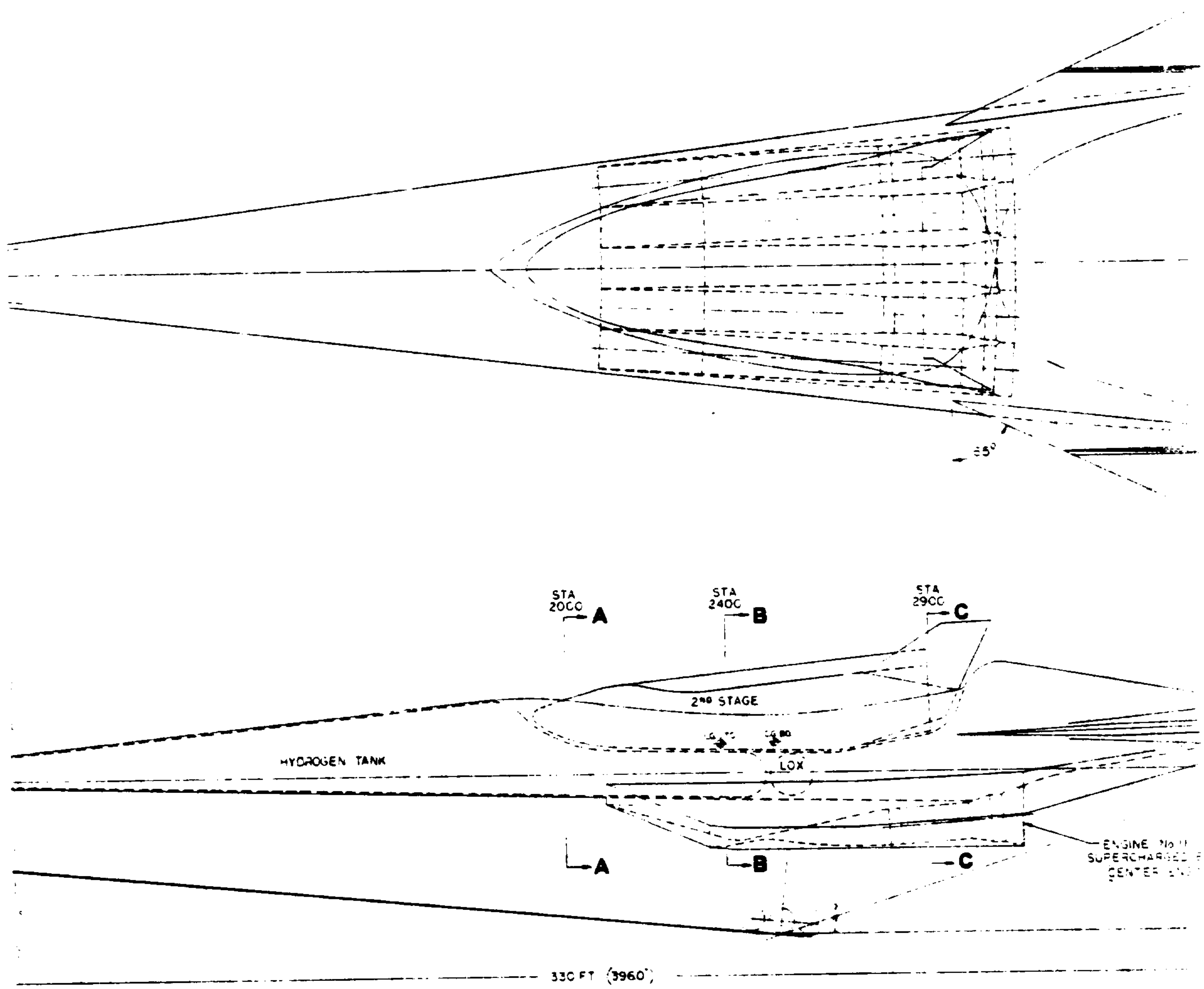
[redacted]



[redacted]

31-1

[redacted]



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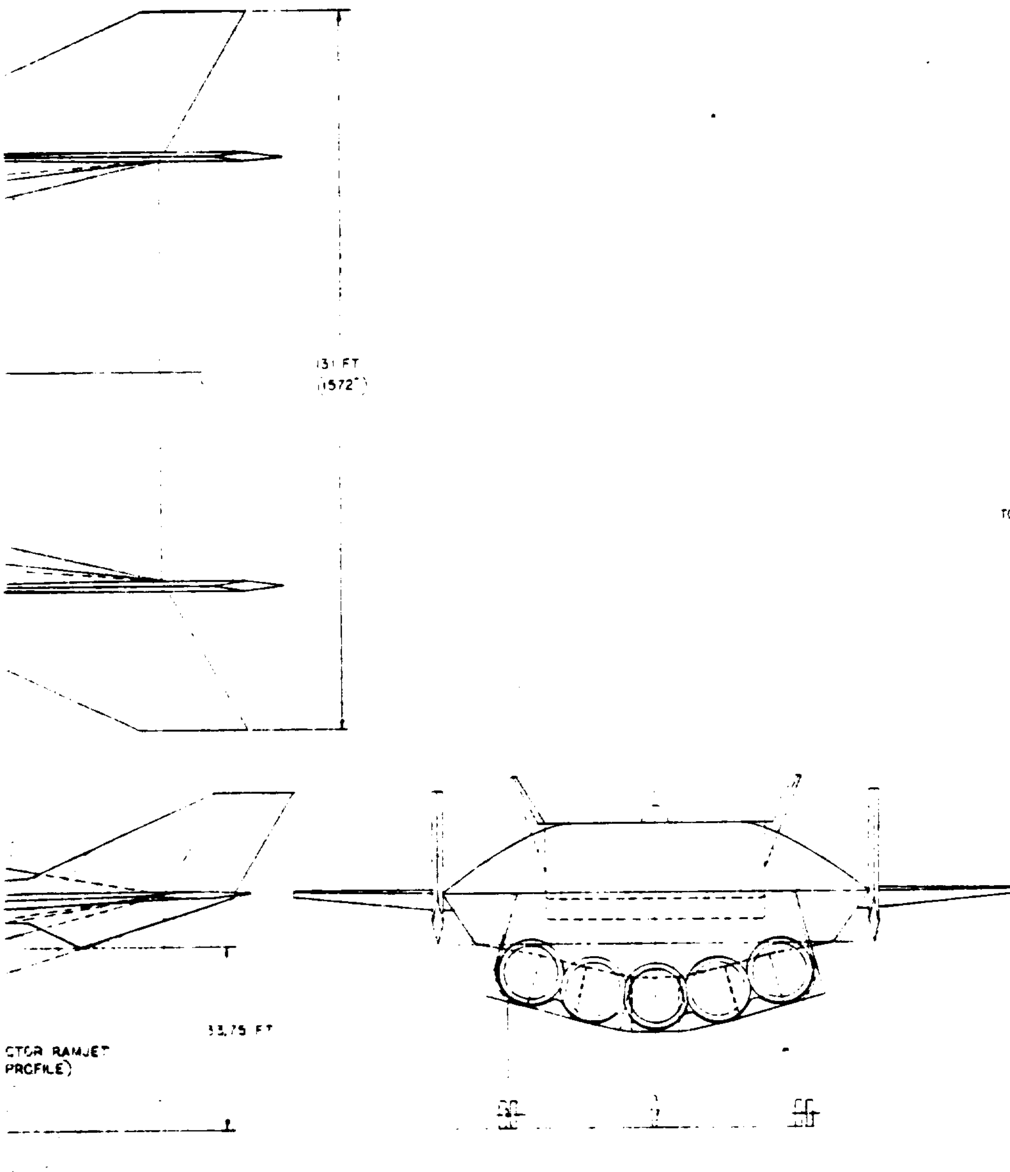

W_0	1 X 10⁶ LBS
BODY AREA	13612 FT^2
HORIZ STAB AREA	2000
STUB WING AREA	612
TOTAL PLANFORM AREA	16224 FT^2
VERTICAL FIN AREA	1200 FT^2
FR	10.2
A_c	350 FT^2
T/W_{SLS}	1.075

SPACECRAFT ENGINEERING
NEW DESIGN DIVISION
COMPOSITE ENGINE STUDY
SYSTEM No. II SERJ
CL655-1-19
LOCKHEED CALIFORNIA COMPANY

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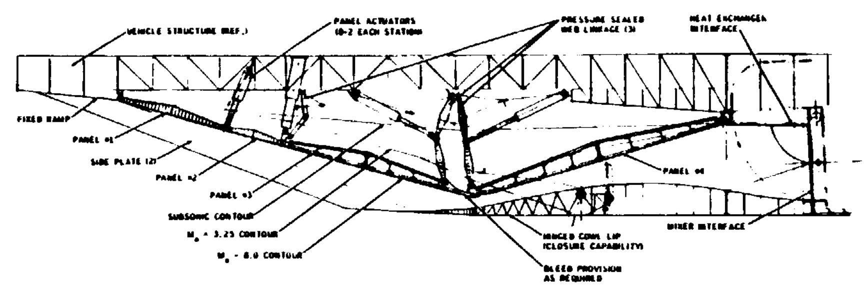
31-2

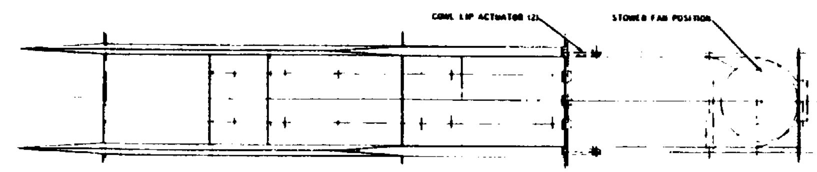
Eng. No. 11

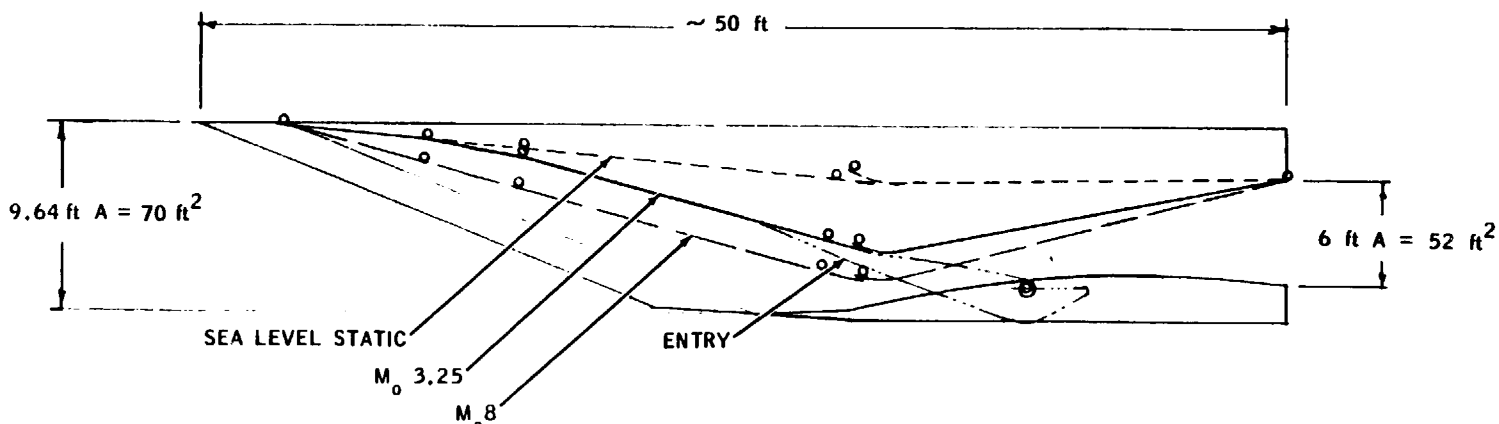
INLET CONTOUR - MACH 0 - 8 CAPABILITY

MECHANIZATION OF TWO-DIMENSIONAL, MOVING PANEL INLET
(MACH 8 CAPABILITY ENGINES, TYPICAL)

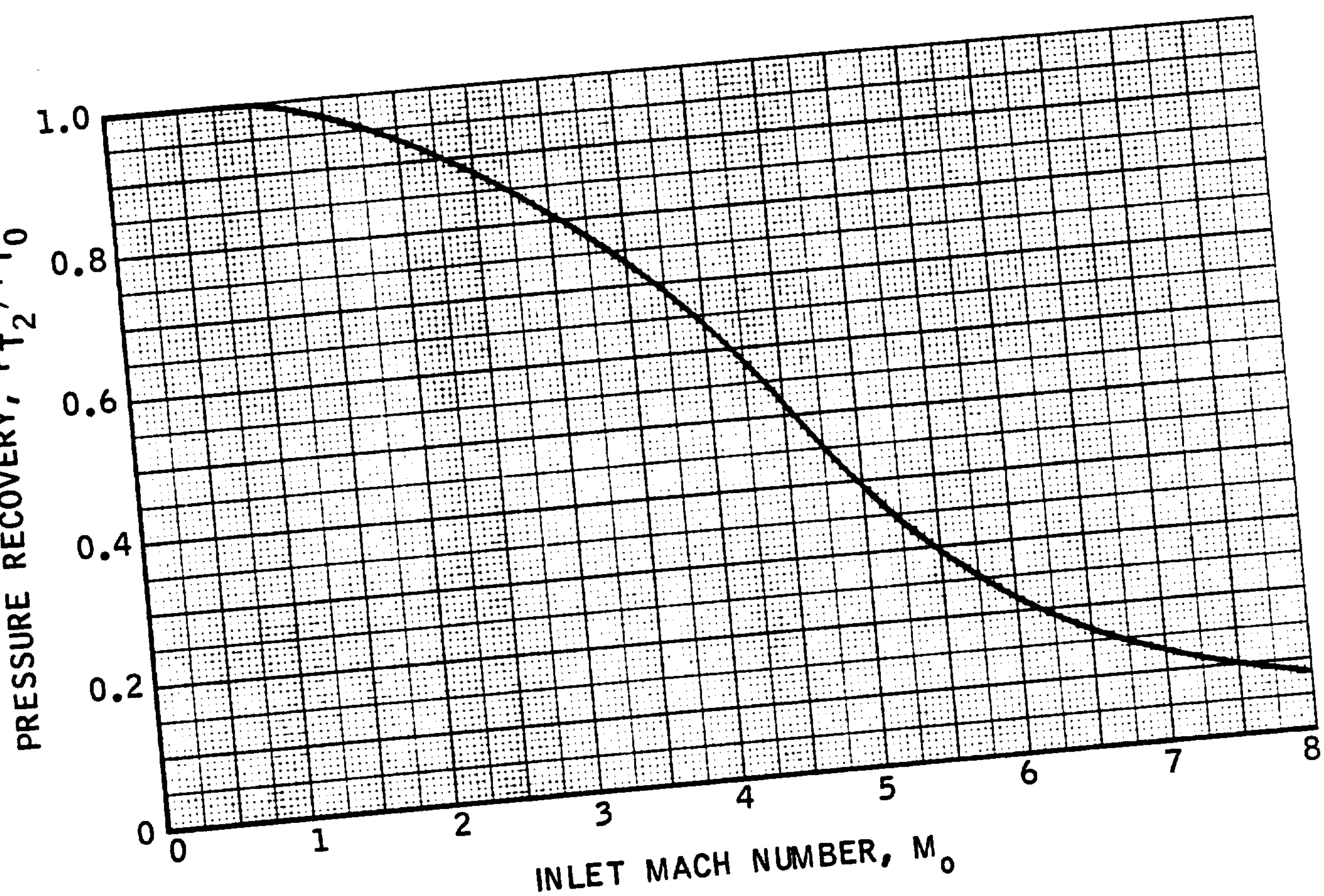
R-21,735



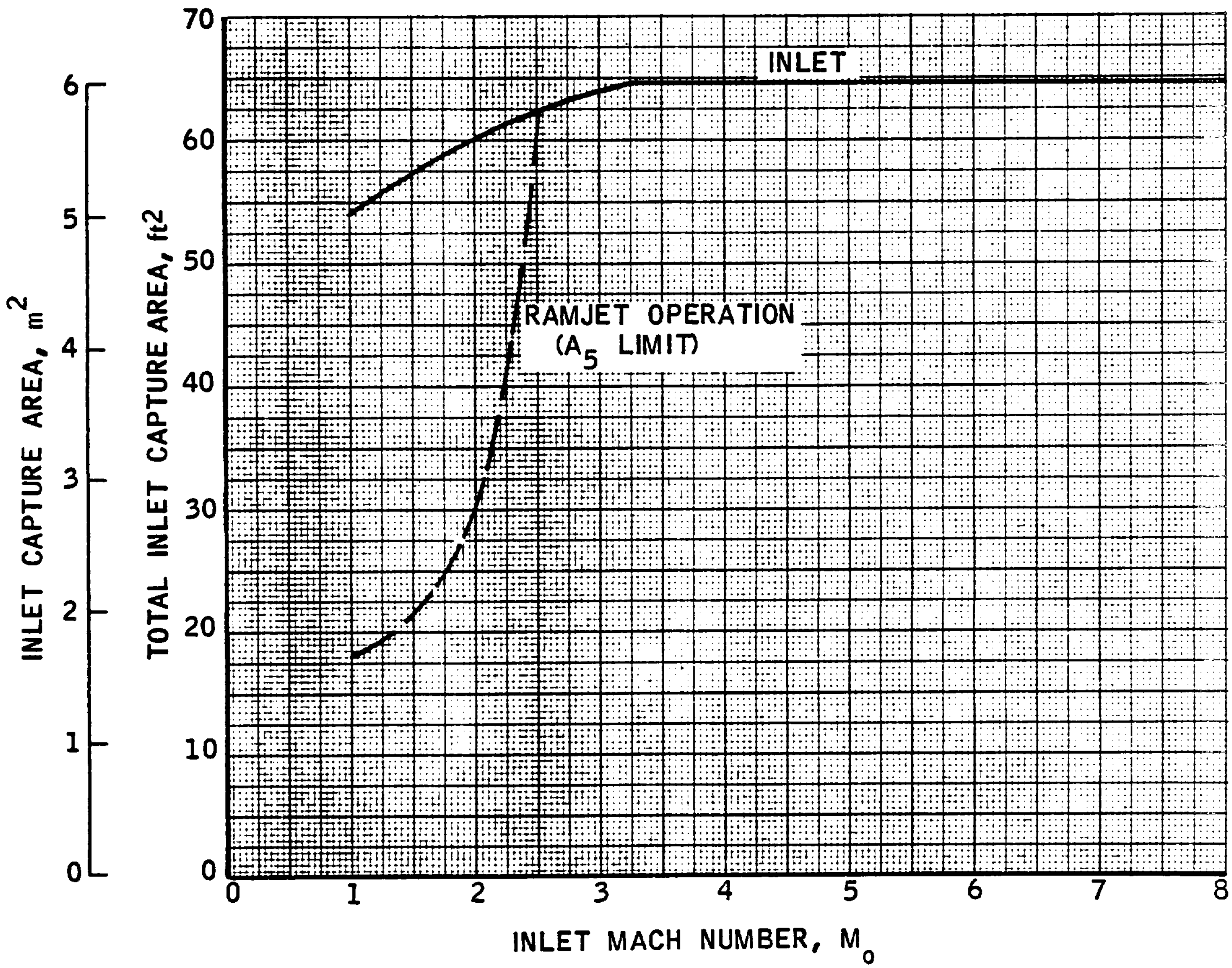




INLET PRESSURE RECOVERY

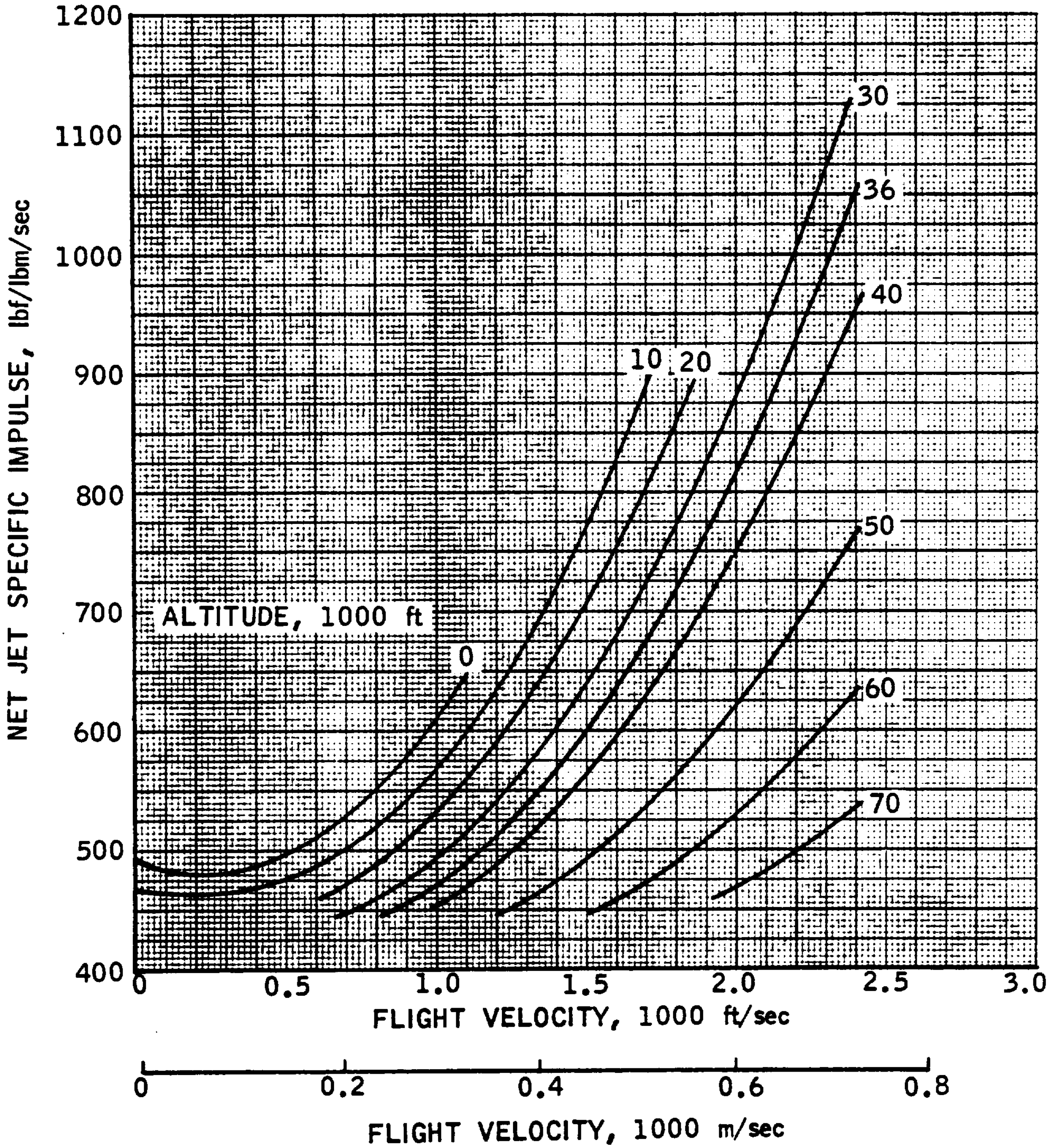


INLET CAPTURE AREA

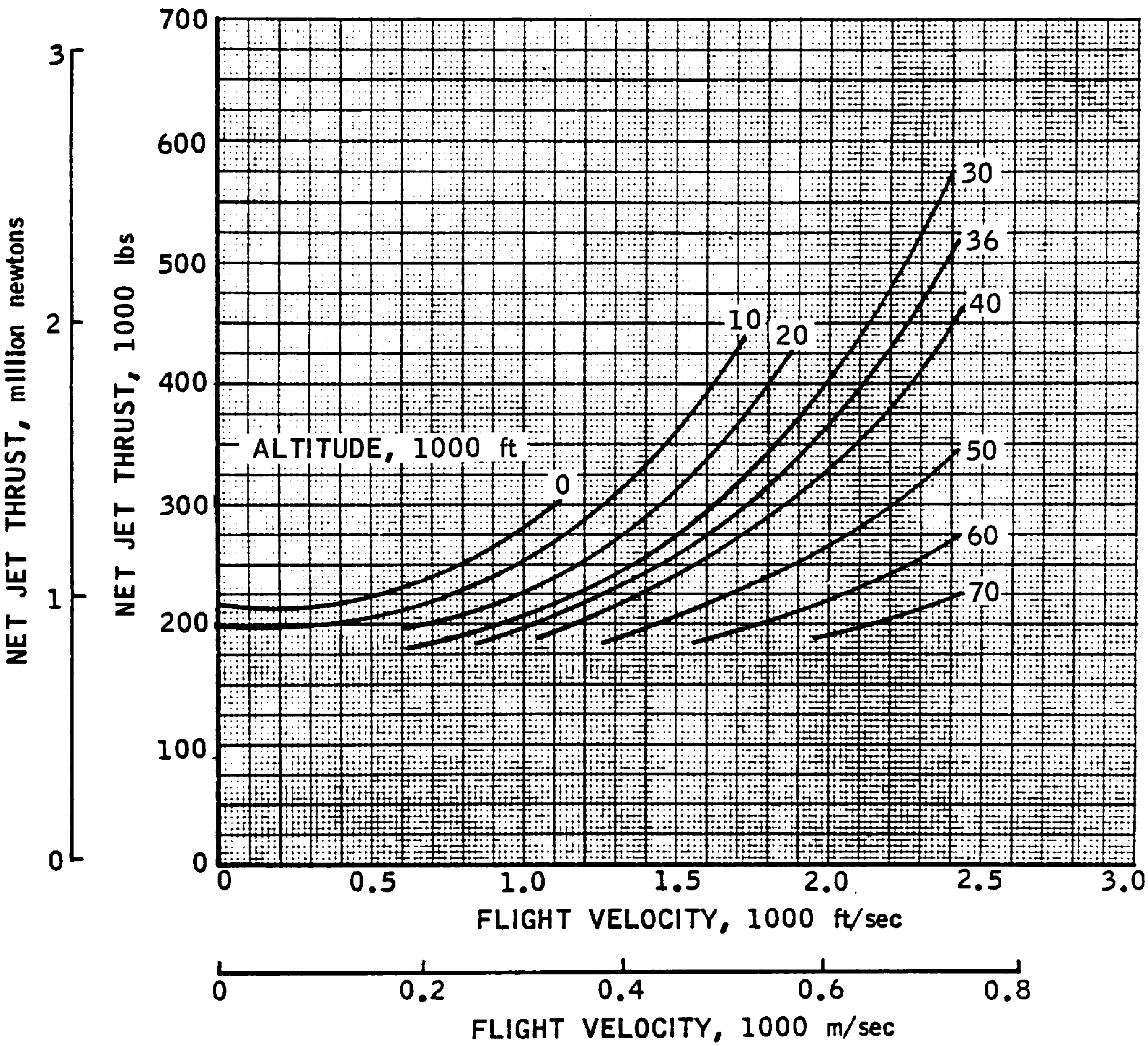


Eng. No. 11

EJECTOR MODE SPECIFIC IMPULSE



EJECTOR MODE THRUST



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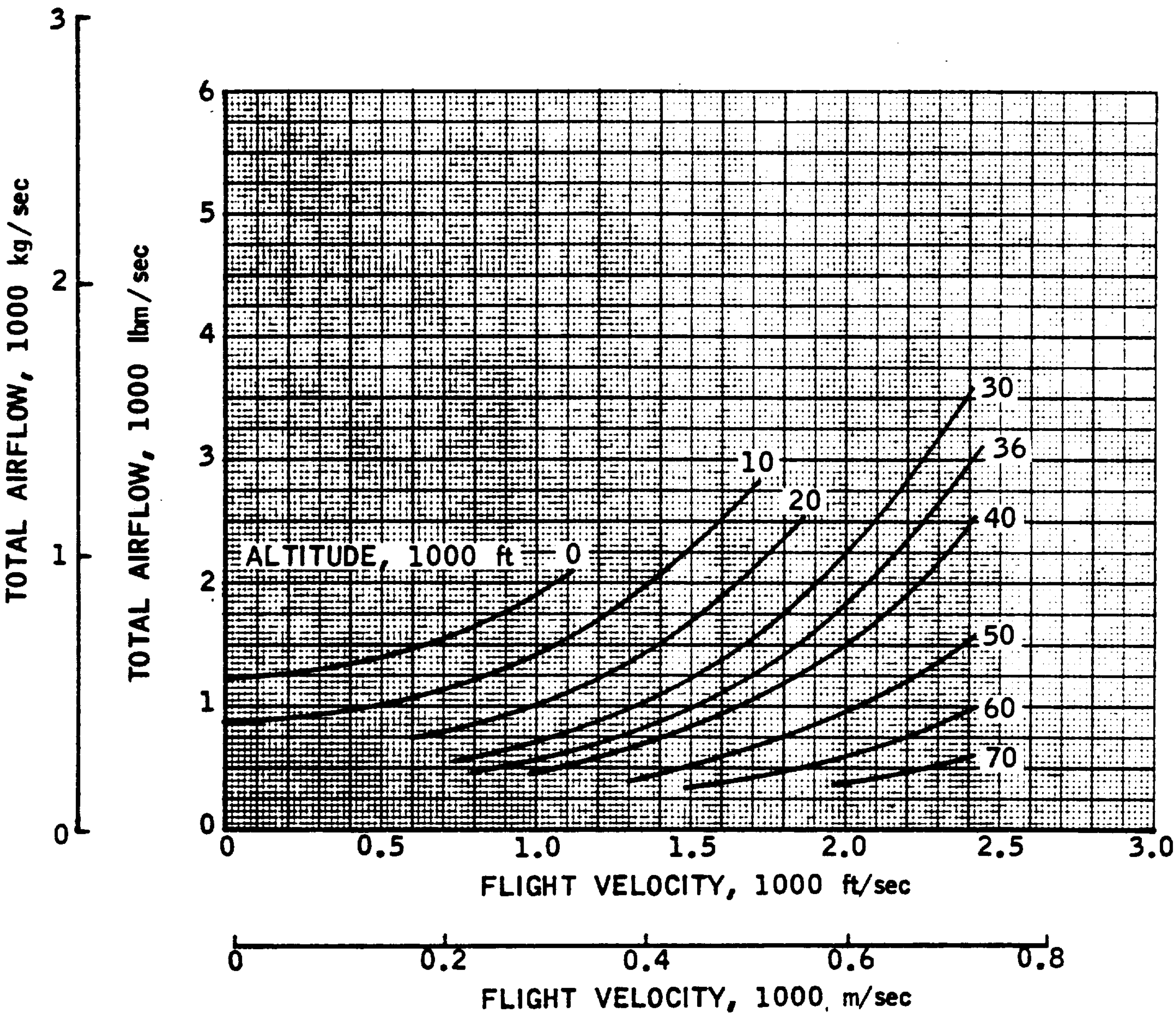
Eng. No. 11

EJECTOR MODE AIRFLOW



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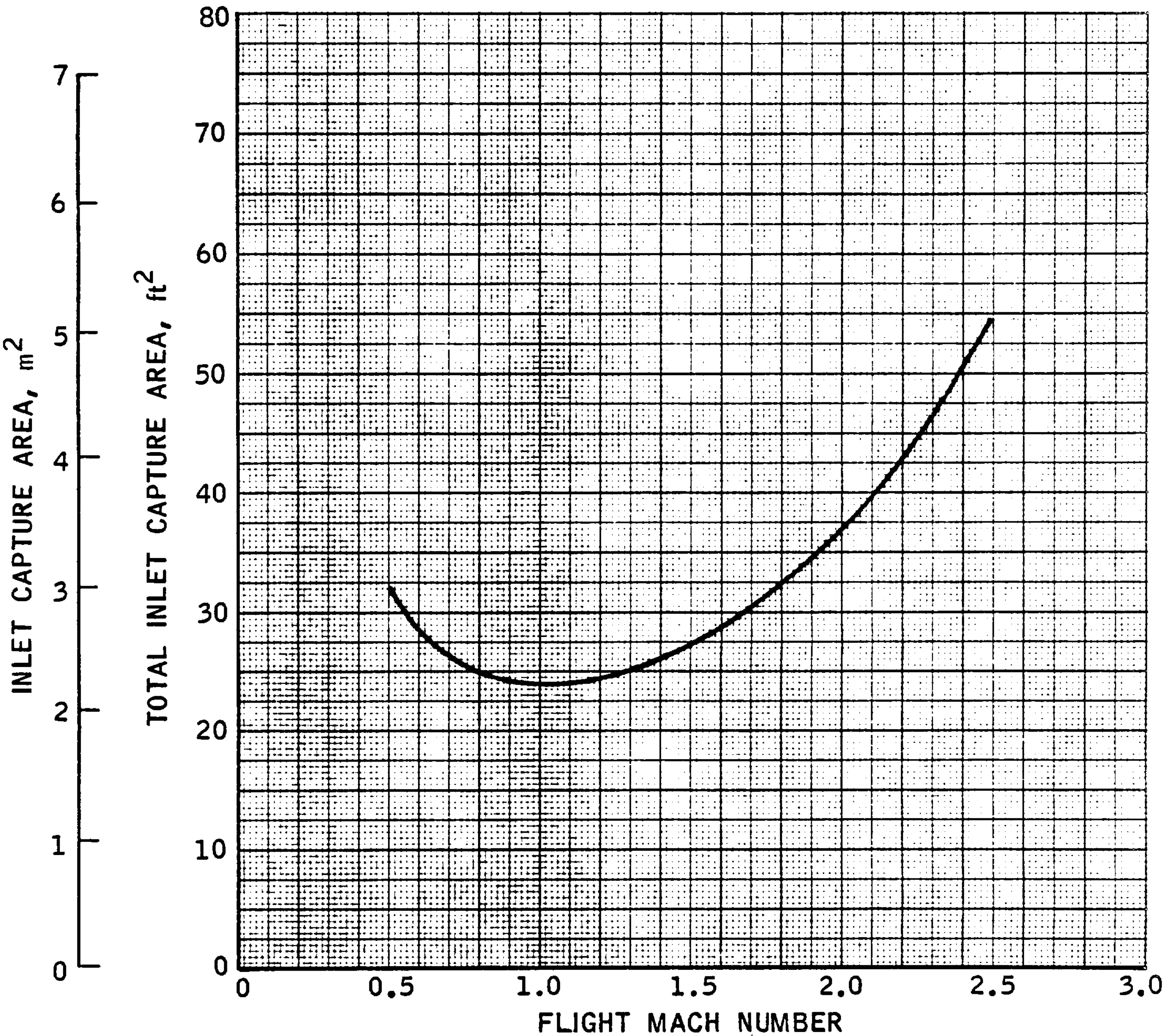
Eng. No. 11

EJECTOR MODE CAPTURE AREA

NOTE: CURVE = UPPER LIMIT



ENGINE- 11 CLASS 2

ESTIMATED PERFORMANCE

MO	VO	HTO	PTO	T	CF	IS	SPC	PT2	H2	P2
				ALTITUDE -	0. FEET					
0.01	11.	124.5	14.7	215101.	1042.70	494.	7.29	19.11	122.4	18.03
0.25	279.	126.0	15.3	212409.	39.68	486.	7.41	19.95	124.0	18.83
0.50	558.	130.7	17.4	223862.	18.74	507.	7.10	22.66	128.6	21.38
0.75	837.	138.5	21.3	252413.	11.83	561.	6.42	27.75	136.2	26.18
1.00	1116.	149.4	27.8	303343.	8.49	655.	5.49	36.16	146.9	34.12
				ALTITUDE -	10000. FEET					
0.01	11.	115.1	10.1	200334.	1413.13	471.	7.64	13.14	113.2	12.40
0.30	322.	117.1	10.8	199746.	44.51	468.	7.69	13.99	115.2	13.20
0.60	644.	123.4	12.9	214210.	20.43	497.	7.25	16.76	121.3	15.81
0.90	966.	133.7	17.1	247285.	12.33	562.	6.41	22.22	131.5	20.97
1.20	1288.	148.2	24.5	305353.	8.46	671.	5.36	31.55	145.8	29.77
1.40	1503.	160.2	32.2	362854.	6.90	774.	4.65	40.88	157.6	38.58
1.60	1718.	174.0	43.0	438745.	5.80	901.	4.00	53.62	171.2	50.60
				ALTITUDE -	20000. FEET					
0.60	622.	115.1	8.6	196544.	28.05	466.	7.72	11.21	113.2	10.57
0.90	933.	124.8	11.4	221096.	16.50	517.	6.96	14.86	122.7	14.02
1.20	1244.	138.3	16.4	262101.	10.87	599.	6.01	21.09	136.0	19.90
1.50	1555.	155.7	24.8	327166.	7.75	722.	4.99	31.29	153.2	29.52
1.80	1867.	177.0	38.8	426928.	5.89	896.	4.02	47.61	174.1	44.94

[redacted]

ENGINE- 11 CLASS 2

ESTIMATED PERFORMANCE

M2	WS	WP	WSWP	WFT	PHP	PHS	V6	PT20	A0	A5	A6
ALTITUDE - 0. FEET											
0.290	1189.	392.	3.03	435.8	1.0	1.000	4291.	1.30	1392.93	63.88	66.44
0.290	1234.	392.	3.15	437.2	1.0	1.000	4318.	1.30	57.83	64.33	67.11
0.290	1377.	392.	3.51	441.7	1.0	1.000	4405.	1.30	32.25	65.44	69.02
0.290	1639.	392.	4.18	449.9	1.0	1.000	4566.	1.30	25.57	66.44	71.99
0.290	2059.	392.	5.25	463.0	1.0	1.000	4801.	1.30	24.07	66.46	76.06
ALTITUDE - 10000. FEET											
0.290	850.	392.	2.17	425.2	1.0	1.000	5095.	1.30	1392.89	58.92	65.56
0.290	897.	392.	2.29	426.7	1.0	1.000	5106.	1.30	48.98	59.64	66.77
0.290	1048.	392.	2.67	431.4	1.0	1.000	5146.	1.30	28.60	61.67	70.51
0.290	1336.	392.	3.40	440.4	1.0	1.000	5233.	1.30	24.28	64.28	76.81
0.290	1803.	392.	4.60	455.0	1.0	1.000	5403.	1.29	24.55	65.39	84.97
0.290	2250.	392.	5.74	468.9	1.0	1.000	5559.	1.27	26.24	64.71	91.58
0.290	2836.	392.	7.23	487.2	1.0	1.000	5735.	1.25	28.89	63.04	99.49
ALTITUDE - 20000. FEET											
0.290	725.	392.	1.85	421.3	1.0	1.000	5953.	1.30	28.60	56.20	72.87
0.290	924.	392.	2.35	427.5	1.0	1.000	5939.	1.30	24.28	59.27	79.85
0.290	1247.	392.	3.18	437.6	1.0	1.000	5959.	1.29	24.55	62.35	89.75
0.290	1746.	392.	4.45	453.2	1.0	1.000	6048.	1.26	27.46	63.53	102.23
0.290	2498.	392.	6.37	476.7	1.0	1.000	6009.	1.23	32.67	62.01	107.01

ENGINE- 11 CLASS 2

ESTIMATED PERFORMANCE

MO	VO	HTO	PTO	T	CF	IS	SPC	PT2	H2	P2
				ALTITUDE - 30000. FEET						
0.70	696.	108.5	6.1	186194.	32.78	449.	8.03	7.89	106.7	7.44
1.10	1094.	122.8	9.3	218237.	16.95	517.	6.97	12.08	120.7	11.40
1.50	1492.	143.3	16.1	275354.	10.10	632.	5.69	20.24	141.0	19.10
1.90	1890.	170.2	29.3	371896.	6.66	812.	4.43	35.54	167.4	33.54
2.40	2388.	212.7	63.9	573730.	4.42	1130.	3.19	72.88	209.3	68.80
				ALTITUDE - 36000. FEET						
0.80	775.	105.7	5.0	182542.	34.32	443.	8.13	6.55	104.0	6.18
1.20	1163.	120.7	8.0	213424.	18.12	509.	7.07	10.32	118.7	9.73
1.60	1550.	141.7	14.1	266086.	10.78	618.	5.83	17.54	139.4	16.55
2.00	1938.	168.7	25.9	351364.	7.00	780.	4.62	31.04	166.0	29.29
2.40	2325.	201.7	48.3	483796.	4.93	1001.	3.60	55.10	198.5	52.01
2.80	2713.	240.7	89.7	682719.	3.70	1275.	2.82	96.81	236.9	91.40
				ALTITUDE - 40000. FEET						
0.80	774.	105.6	4.2	175631.	39.99	428.	8.41	5.41	103.8	5.10
1.40	1355.	130.3	8.7	222315.	15.71	530.	6.80	11.04	128.1	10.42
2.00	1936.	168.5	21.4	318245.	7.68	721.	5.00	25.63	165.7	24.19
2.50	2420.	210.6	46.6	462672.	4.86	969.	3.72	52.43	207.2	49.49
3.00	2904.	262.1	100.3	697434.	3.39	1290.	2.79	104.69	258.0	98.86

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ENGINE- 11 CLASS 2

ESTIMATED PERFORMANCE

M2	WS	WP	WSWP	WFT	PHP	PHS	V6	PT2O	AU	A5	A6
ALTITUDE - 30000. FEET											
0.290	525.	392.	1.34	415.1	1.0	1.000	6817.	1.30	26.34	51.66	81.18
0.290	757.	392.	1.93	422.3	1.0	1.000	6702.	1.29	24.15	56.21	93.01
0.290	1176.	392.	3.00	435.4	1.0	1.000	6538.	1.26	27.46	60.70	107.18
0.290	1900.	392.	4.84	458.0	1.0	1.000	6185.	1.21	34.93	61.65	107.25
0.290	3500.	392.	8.92	507.9	1.0	1.000	6032.	1.14	50.74	57.21	106.97
ALTITUDE - 36000. FEET											
0.290	442.	392.	1.13	412.5	1.0	1.000	7340.	1.30	24.99	49.35	89.92
0.290	652.	392.	1.66	419.0	1.0	1.000	7172.	1.29	24.55	54.06	103.38
0.290	1025.	392.	2.61	430.7	1.0	1.000	6709.	1.25	28.89	58.89	107.07
0.290	1666.	392.	4.25	450.7	1.0	1.000	6299.	1.20	37.50	60.86	107.26
0.290	2714.	392.	6.92	483.4	1.0	1.000	6115.	1.14	50.73	58.37	107.26
0.290	4382.	392.	11.17	535.5	1.0	1.000	6082.	1.08	69.95	53.85	107.29
ALTITUDE - 40000. FEET											
0.290	365.	392.	0.93	410.1	1.0	1.000	7727.	1.30	24.99	46.83	94.86
0.290	672.	392.	1.71	419.7	1.0	1.000	7241.	1.27	26.24	53.78	107.01
0.290	1377.	392.	3.51	441.7	1.0	1.000	6496.	1.20	37.50	59.13	107.24
0.290	2529.	392.	6.45	477.7	1.0	1.000	6201.	1.12	54.89	57.03	106.92
0.290	4552.	392.	11.60	540.8	1.0	1.000	6157.	1.04	81.89	51.69	106.93

ENGINE- 11 CLASS 2

ESTIMATED PERFORMANCE

MO	VO	HTO	PTO	T	CF	IS	SPC	PT2	H2	P2
				ALTITUDE -	50000. FEET					
1.00	968.	112.3	3.2	170719.	41.65	419.	8.59	4.16	110.4	3.93
1.50	1452.	135.7	6.2	202181.	19.17	489.	7.36	7.83	133.5	7.39
2.00	1936.	168.5	13.2	256872.	10.00	604.	5.96	15.89	165.7	14.99
2.50	2420.	210.6	28.9	347300.	5.89	776.	4.64	32.49	207.2	30.67
3.00	2904.	262.1	62.2	493233.	3.87	1013.	3.55	64.89	258.0	61.27
				ALTITUDE -	60000. FEET					
1.00	968.	112.3	2.0	159259.	62.66	394.	9.13	2.58	110.4	2.44
1.50	1452.	135.7	3.9	180255.	27.57	442.	8.14	4.86	133.5	4.58
2.00	1936.	168.5	8.2	216486.	13.60	521.	6.90	9.85	165.7	9.29
2.50	2420.	210.6	17.9	274703.	7.51	640.	5.62	20.15	207.2	19.02
3.00	2904.	262.1	38.5	365903.	4.64	807.	4.46	40.23	258.0	37.99
				ALTITUDE -	70000. FEET					
2.00	1942.	169.5	5.1	189229.	19.15	463.	7.78	6.11	166.7	5.77
2.40	2330.	202.6	9.5	218378.	11.31	526.	6.85	10.85	199.3	10.24
2.80	2719.	241.7	17.7	259667.	7.14	610.	5.90	19.06	238.0	18.00
3.00	2913.	263.6	23.9	285552.	5.83	660.	5.45	24.96	259.5	23.57

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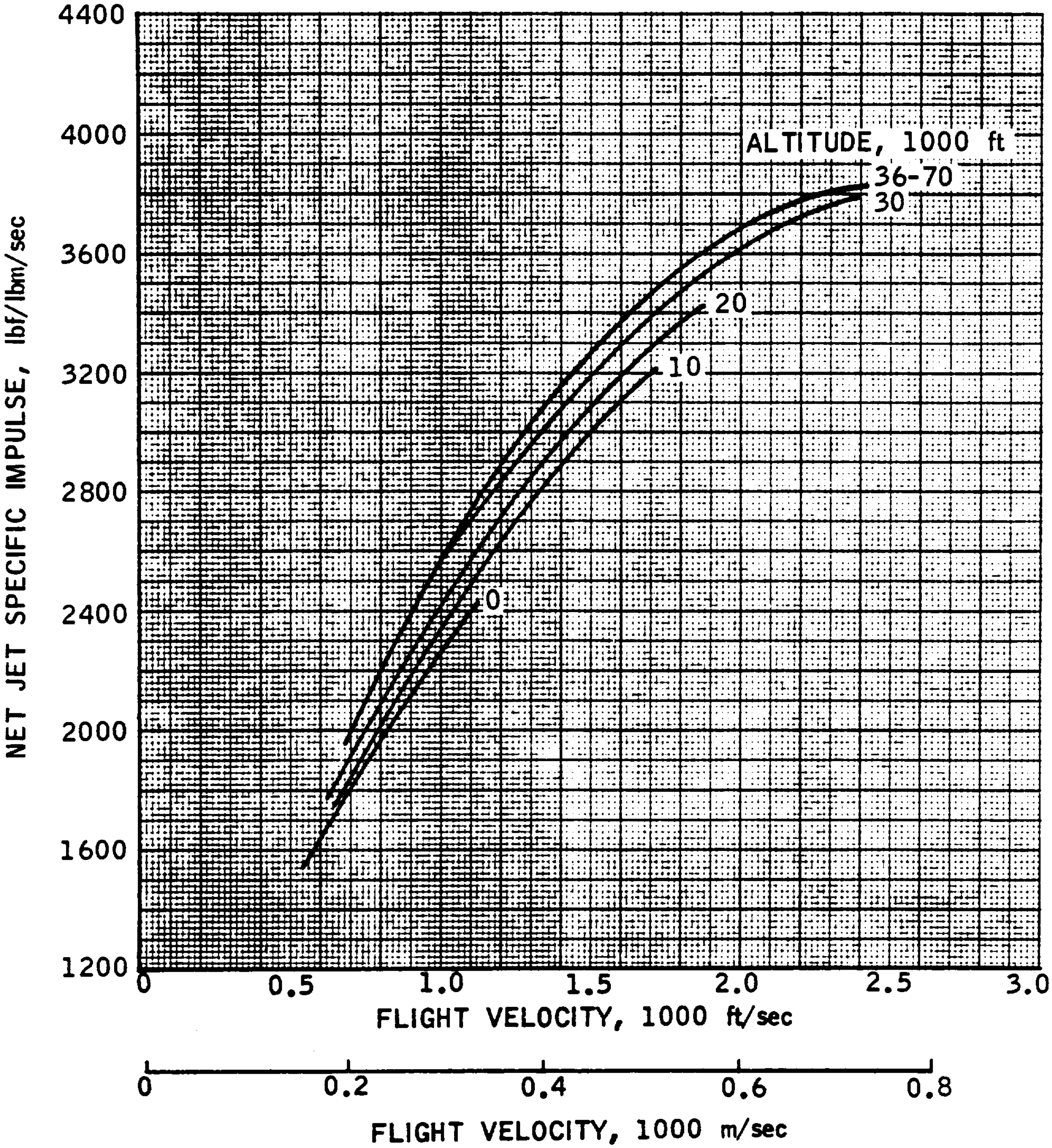
ENGINE- 11 CLASS 2

ESTIMATED PERFORMANCE

M2	WS	WP	WSWP	WFT	PHP	PHS	V6	PT20	A0	A5	A6
ALTITUDE - 50000. FEET											
0.290	272.	392.	0.69	407.2	1.0	1.000	8351.	1.30	24.07	43.22	107.01
0.290	467.	392.	1.19	413.3	1.0	1.000	7748.	1.26	27.46	48.61	107.09
0.290	853.	392.	2.18	425.3	1.0	1.000	7068.	1.20	37.50	53.89	107.31
0.290	1568.	392.	4.00	447.6	1.0	1.000	6568.	1.12	54.89	55.22	106.83
0.290	2821.	392.	7.19	486.8	1.0	1.000	6370.	1.04	81.89	51.81	106.81
ALTITUDE - 60000. FEET											
0.290	169.	392.	0.43	404.0	1.0	1.000	8810.	1.30	24.07	38.78	107.19
0.290	290.	392.	0.74	407.7	1.0	1.000	8318.	1.26	27.46	43.26	107.03
0.290	529.	392.	1.35	415.2	1.0	1.000	7669.	1.20	37.50	48.51	107.15
0.290	972.	392.	2.48	429.0	1.0	1.000	7062.	1.12	54.89	51.98	107.32
0.290	1749.	392.	4.46	453.3	1.0	1.000	6681.	1.04	81.89	51.18	106.74
ALTITUDE - 70000. FEET											
0.290	327.	392.	0.83	408.9	1.0	1.000	8234.	1.20	37.50	43.58	107.04
0.290	533.	392.	1.36	415.3	1.0	1.000	7735.	1.14	50.73	47.12	107.06
0.290	861.	392.	2.19	425.6	1.0	1.000	7284.	1.08	69.95	49.19	107.11
0.290	1082.	392.	2.76	432.5	1.0	1.000	7113.	1.04	81.89	49.32	107.24

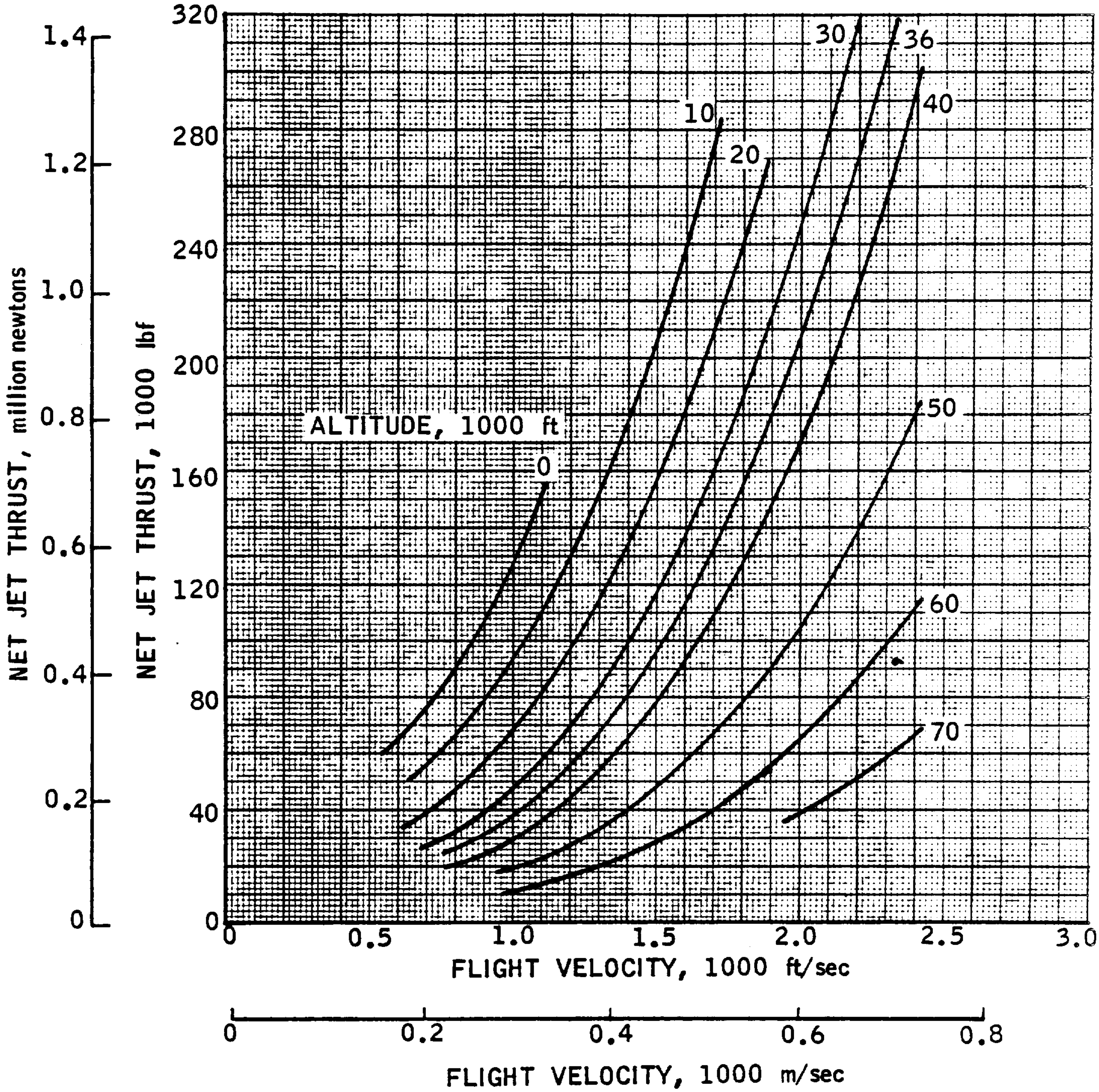
Eng. No. 11

FAN RAMJET SPECIFIC IMPULSE

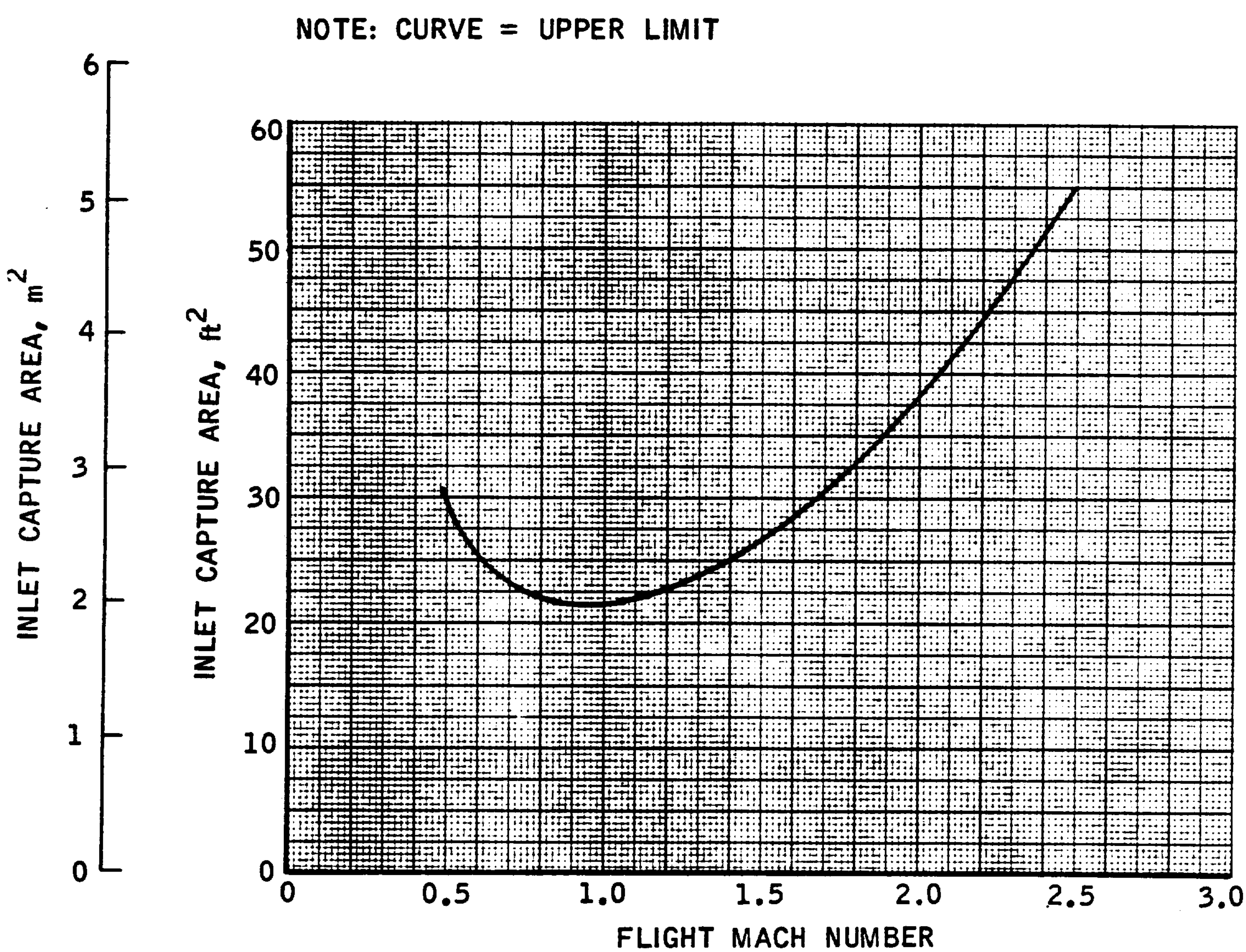


Eng. No. 11

FAN RAMJET THRUST



FAN RAMJET CAPTURE AREA



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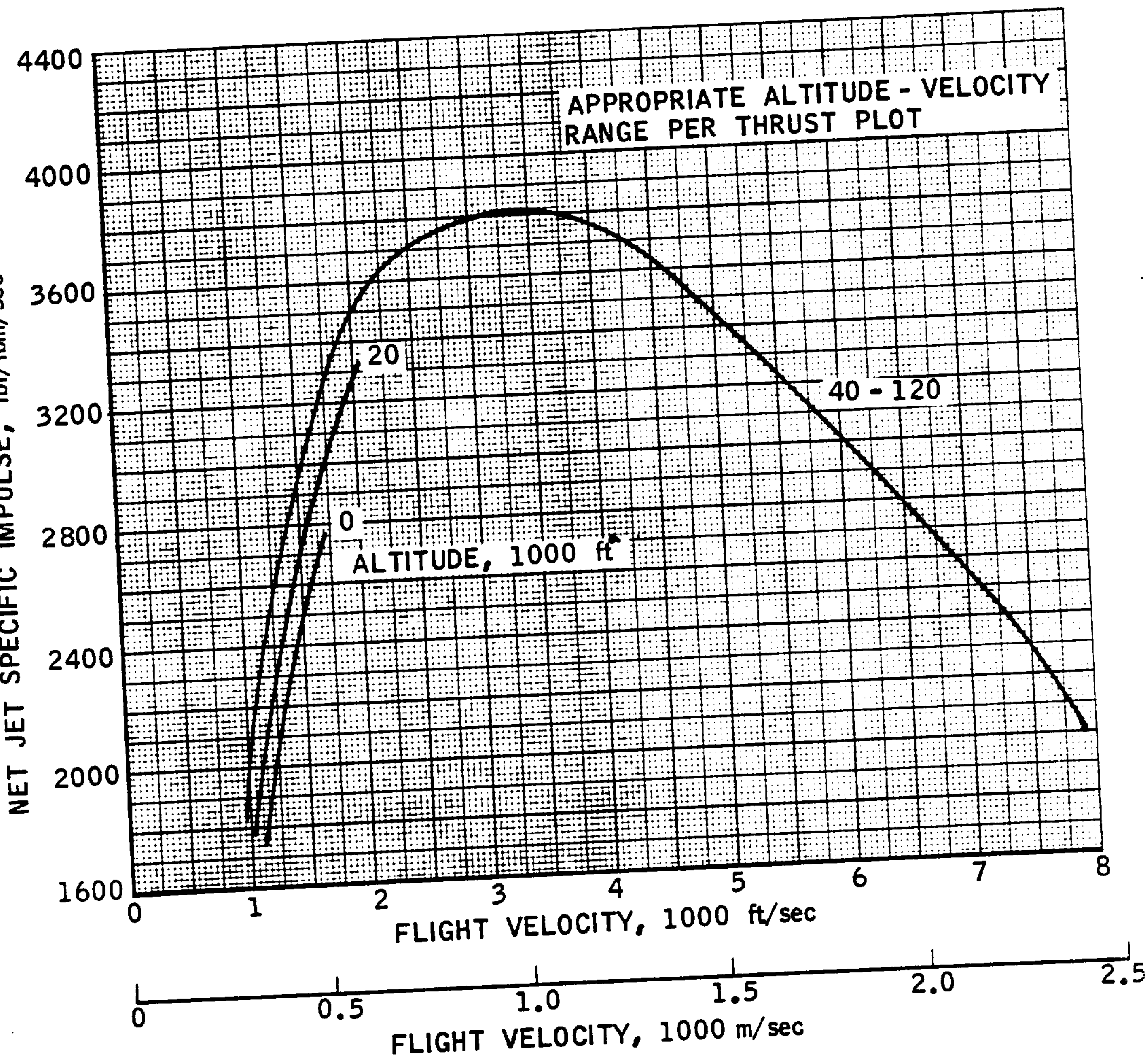
RAMJET SPECIFIC IMPULSE

SUBSONIC COMBUSTION

NO PRESSURE FIELD

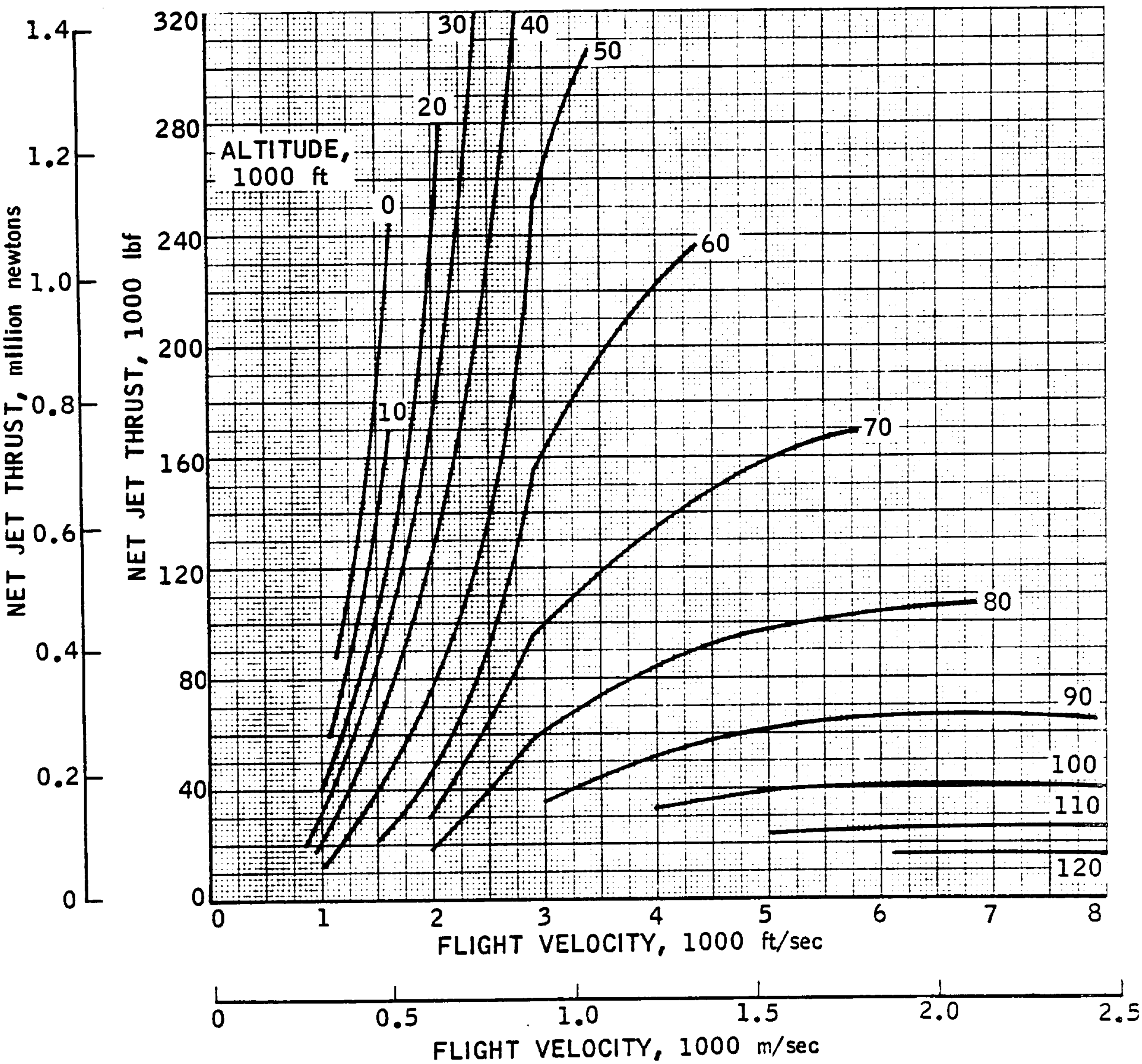


Eng. No. 11

RAMJET THRUST

SUBSONIC COMBUSTION

NO PRESSURE FIELD



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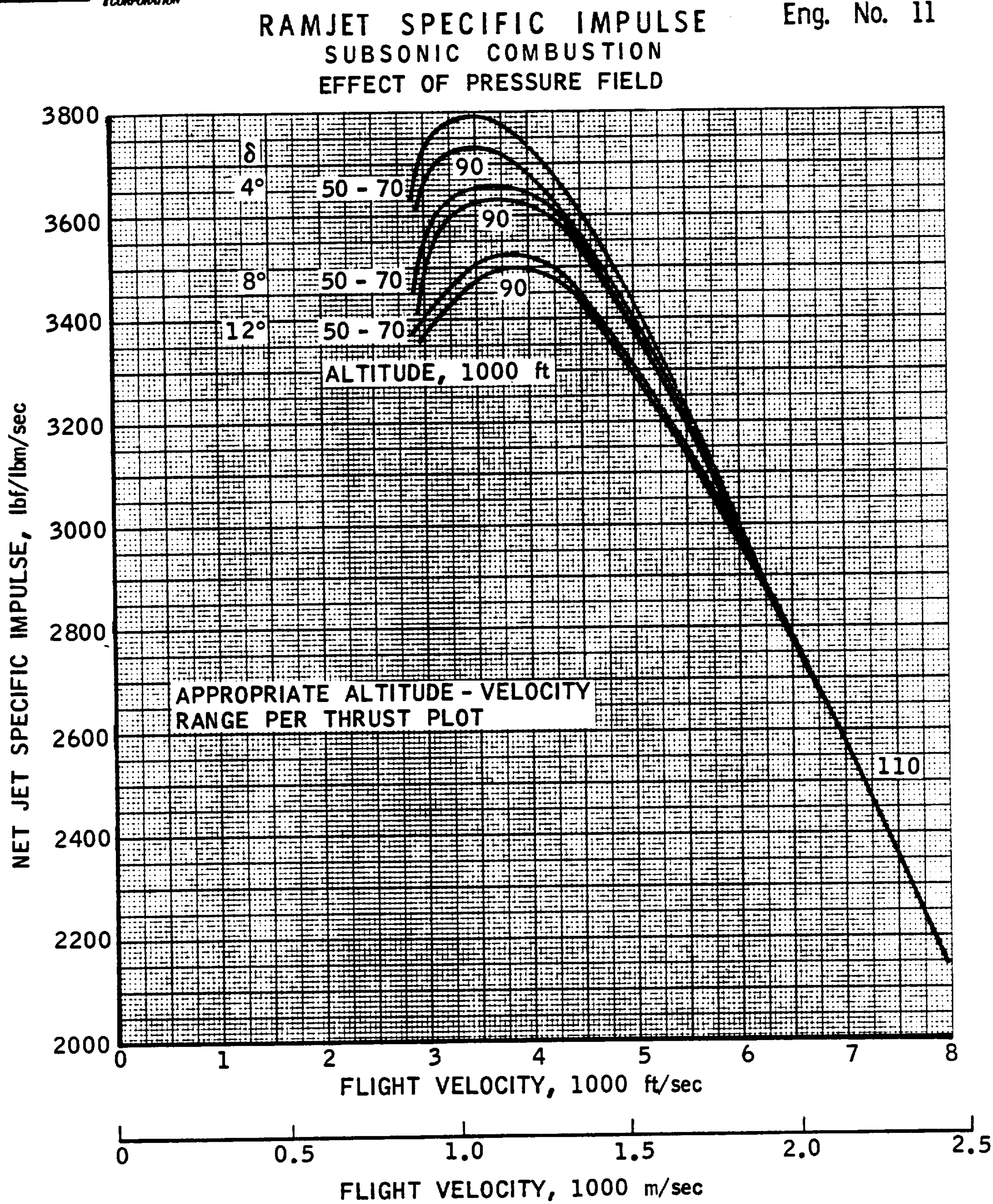
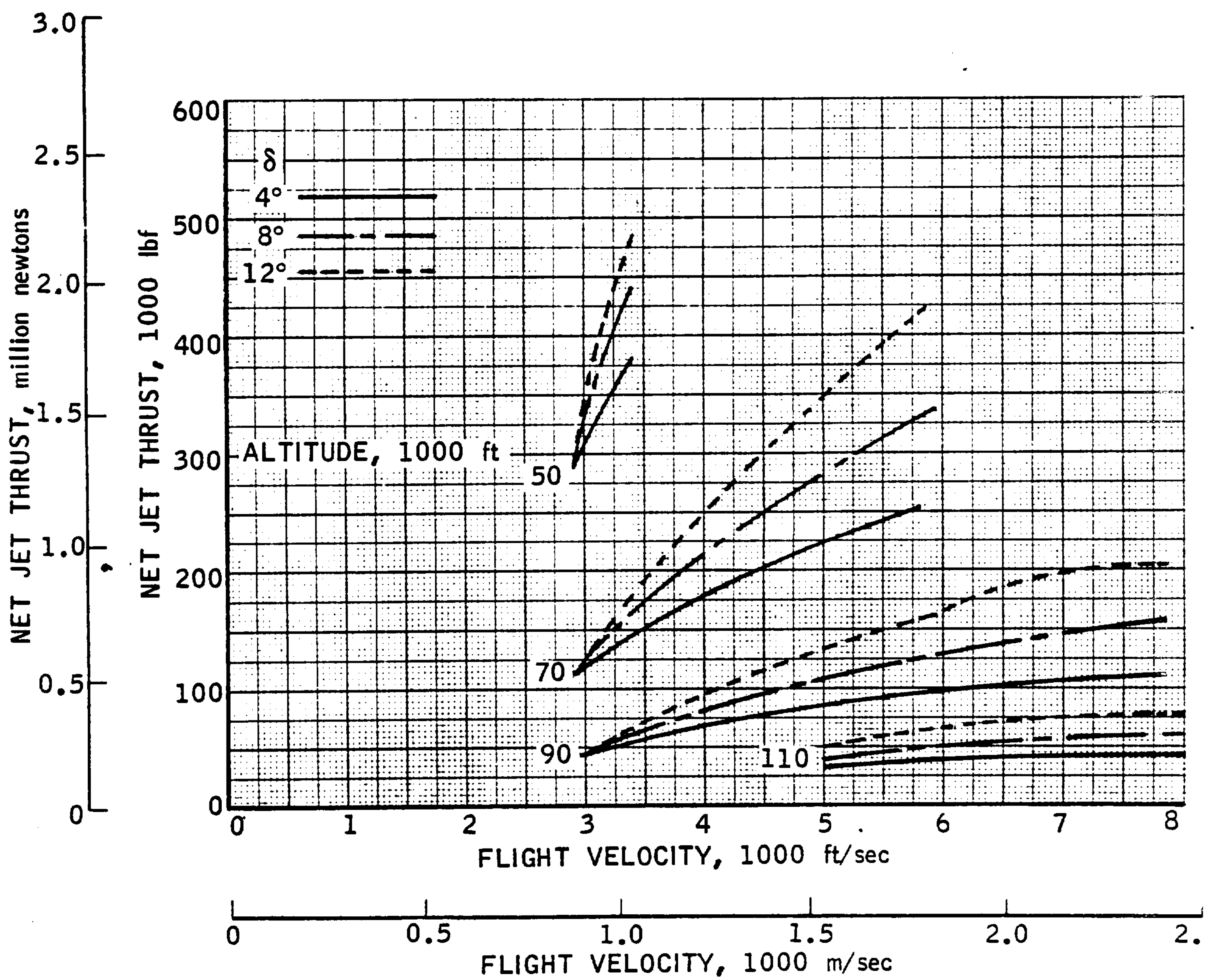


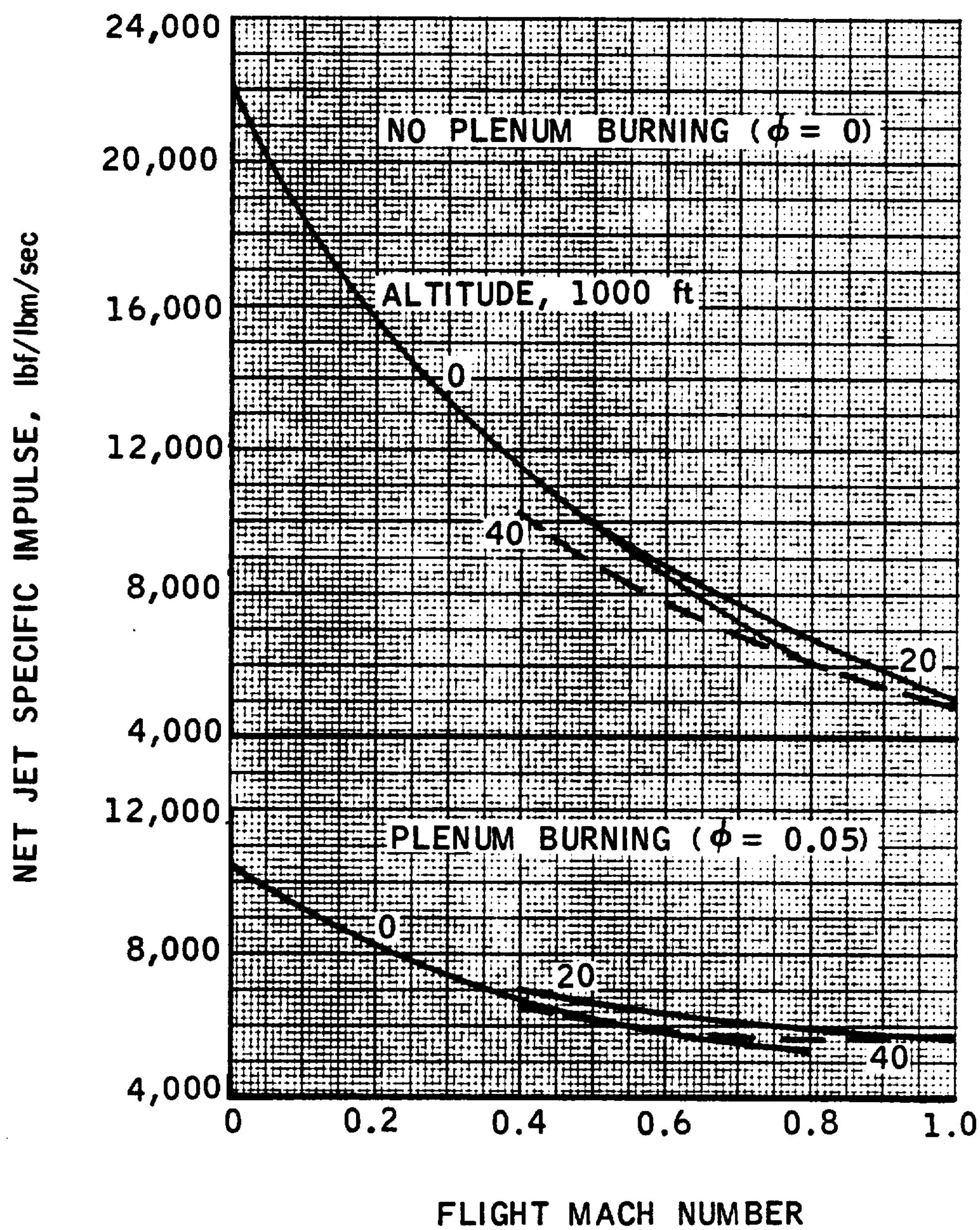
RAMJET THRUST

SUBSONIC COMBUSTION

EFFECT OF PRESSURE FIELD

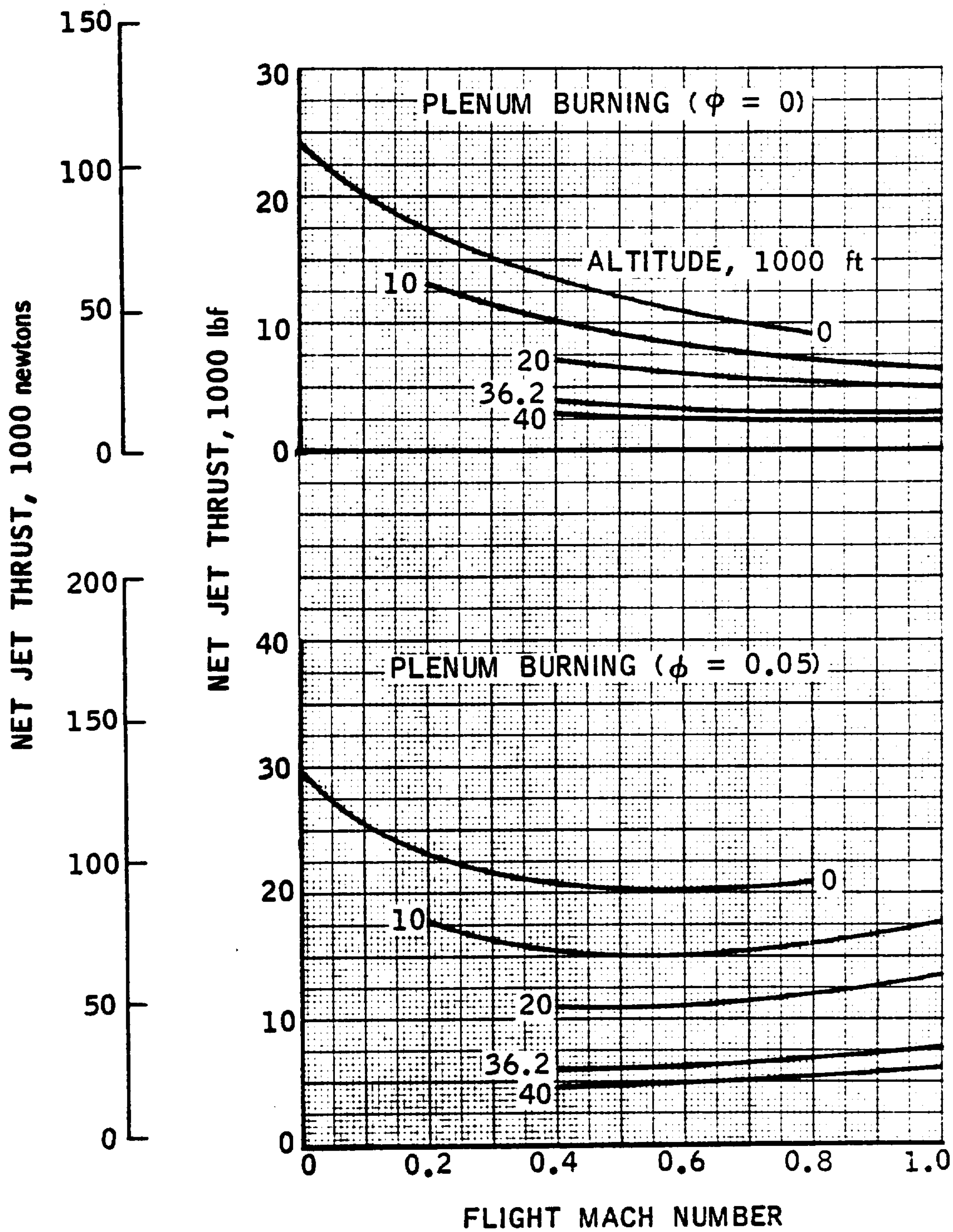


FAN OPERATION SPECIFIC IMPULSE

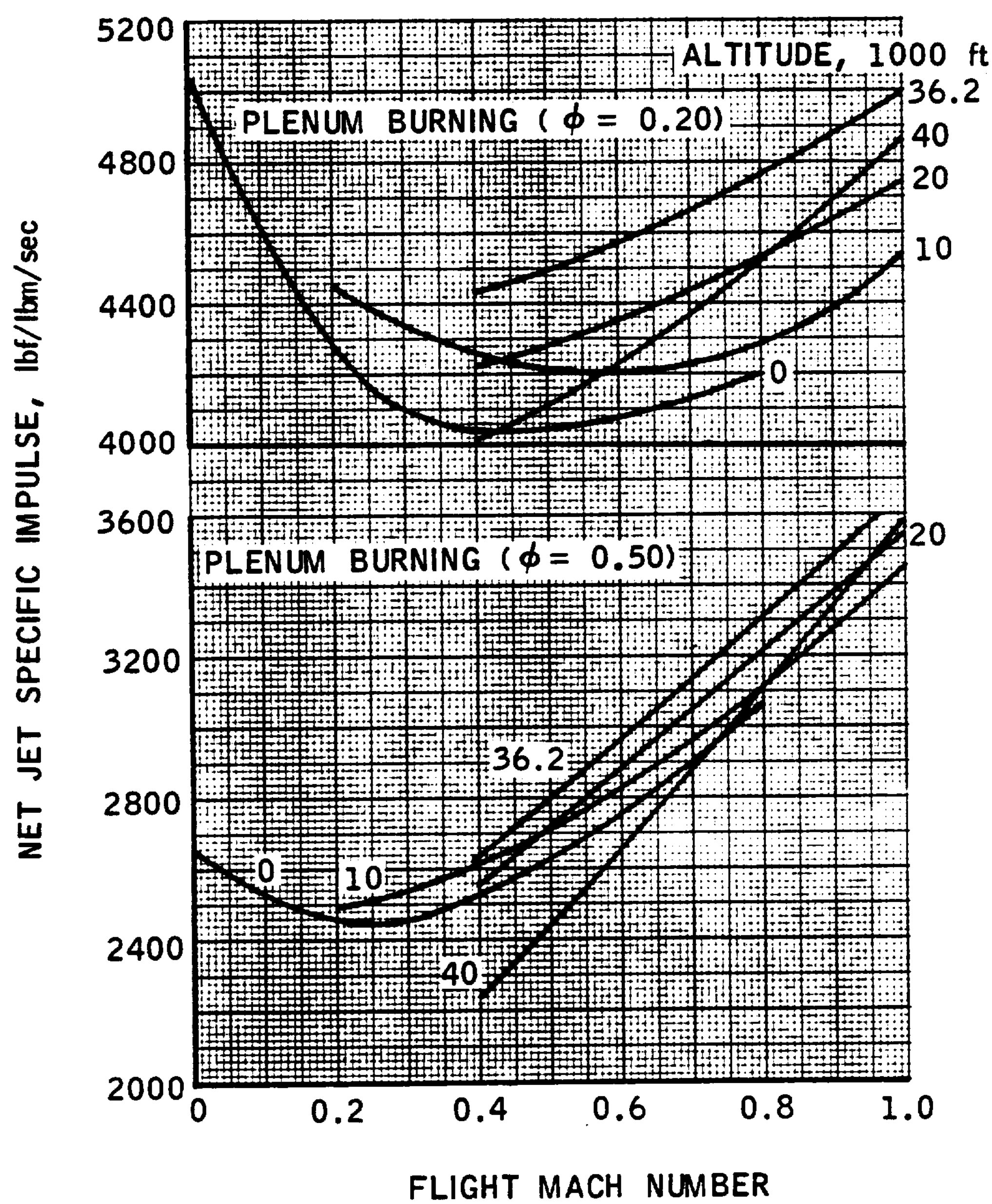


Eng. No. 11

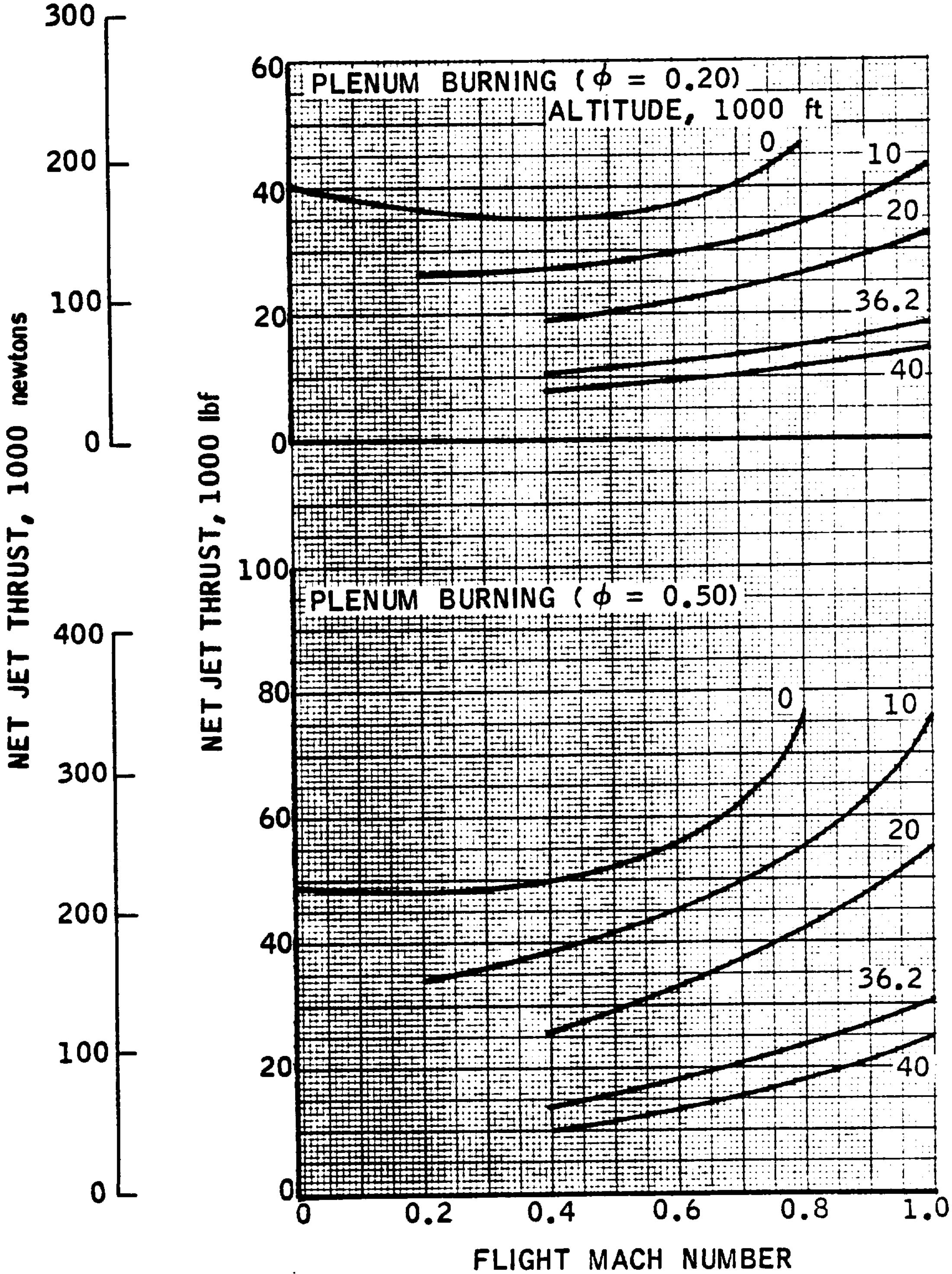
FAN OPERATION THRUST



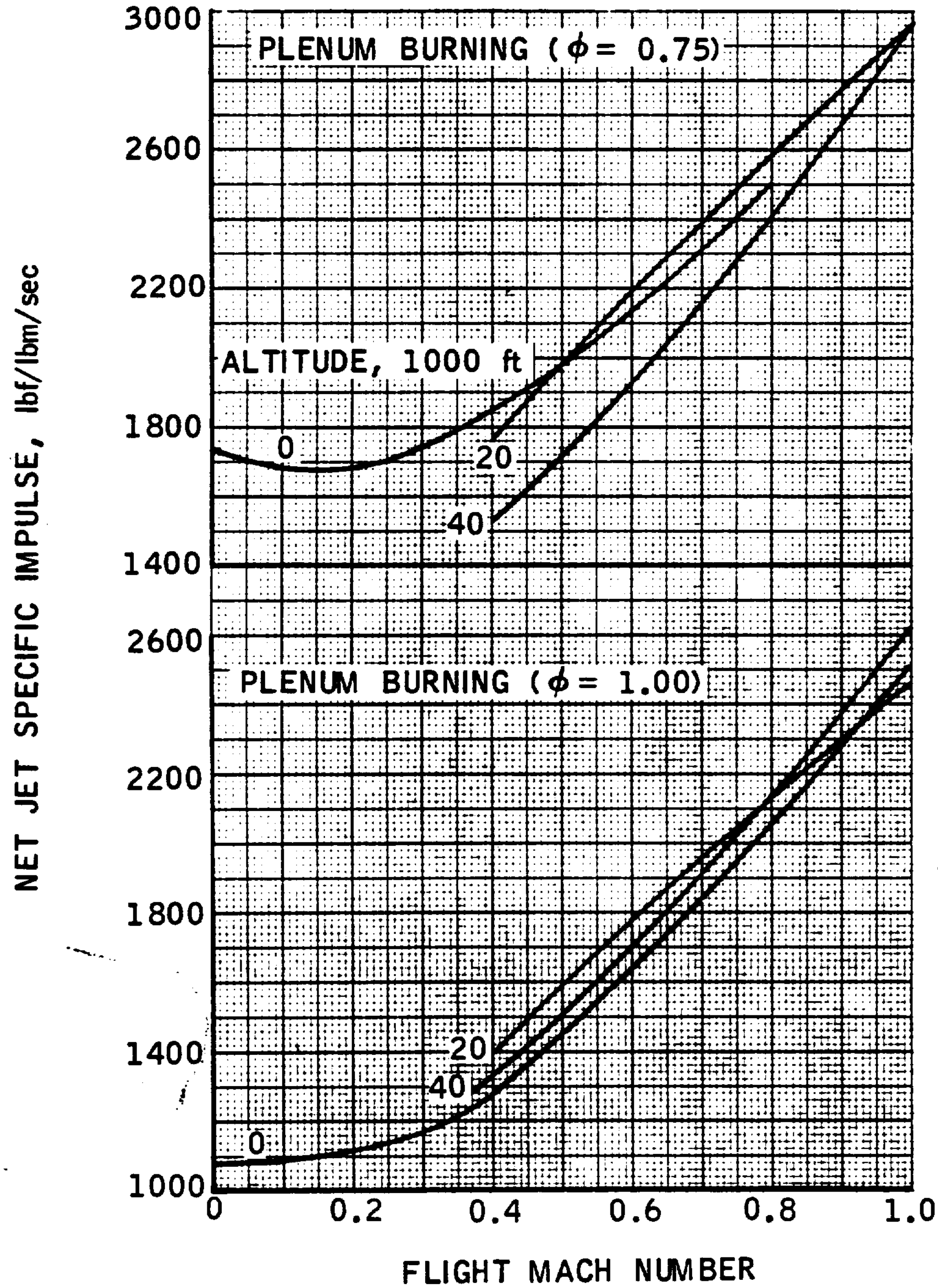
FAN OPERATION SPECIFIC IMPULSE



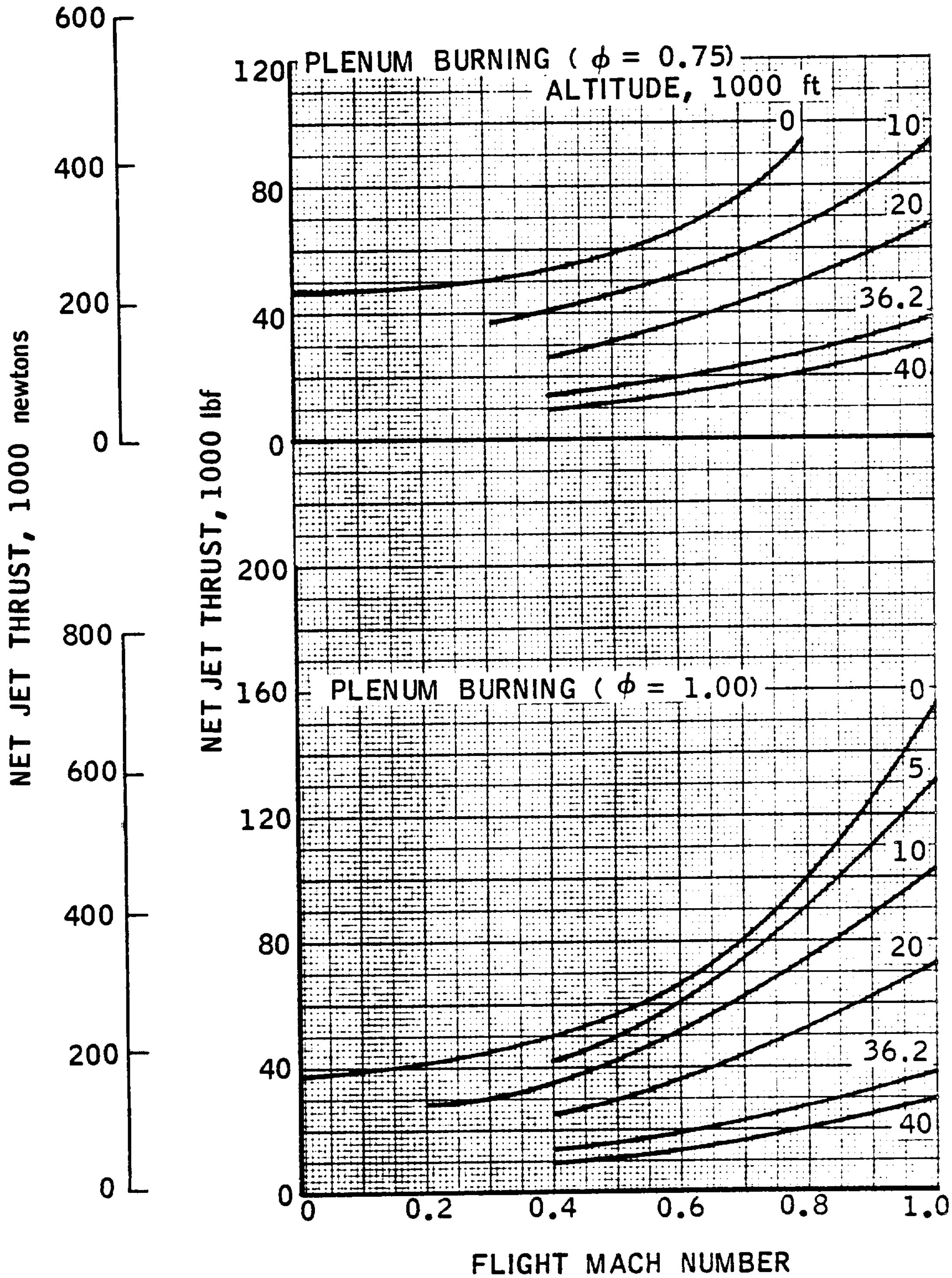
FAN OPERATION THRUST



FAN OPERATION SPECIFIC IMPULSE



FAN OPERATION THRUST



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SUMMARY: SENSITIVITY ANALYSIS - BASES

The performance data shown in the present report, as well as in the Class 0 and 1 engine documentation (References 1 and 2), was computed on the basis of a singular set of internal component efficiencies, as well as stated operating points (e.g., design mass flow ratio, W_s/W_p). Component sensitivity studies were conducted as a major effort within the Class 2 study phase. The bases for the analysis are given here, followed immediately by the results.

The approach used was to define baseline performance, specific impulse and thrust (both net jet), for a reference trajectory. This was accomplished for each of the engine's operating modes over the normal range of flight velocities for that mode. It is appropriate here, to comment to the point that sensitivity studies of trajectory effects, per se, are already intrinsic in the previously displayed performance maps.

Proceeding from this basis of specific impulse and thrust discrete trends, each of the important engine variables was perturbed from the baseline value, e.g., afterburner combustion efficiency: Baseline value - 0.95, sensitivity excursions - 0.85 and 1.00. All of the remaining variables were essentially held at the baseline, or nominal value. Any exception to this resulted from the engine performance computer program's automatic compensation characteristics which, in some instances "retunes" some of the engine internal variables. The extent and implications of this situation are covered in the main technical report (Reference 3).

This section presents the following bases for the sensitivity analysis results to be given subsequently:

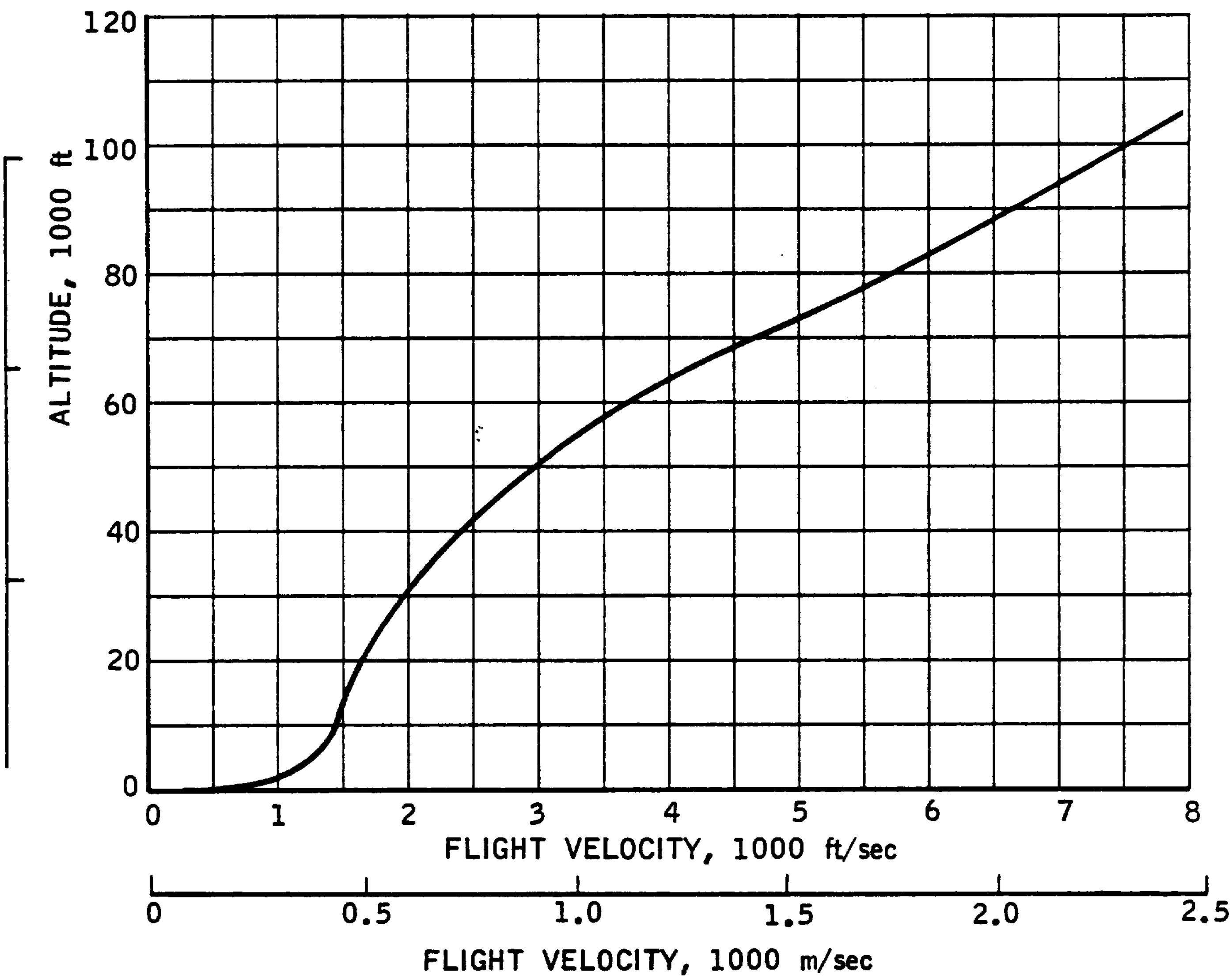
1. Reference trajectories

2. Baseline specific impulse (on reference trajectory)

3. Baseline thrust (on reference trajectory)

4. Ranges of sensitivity variables, with reference to the baseline values (both curve and tabular presentation)

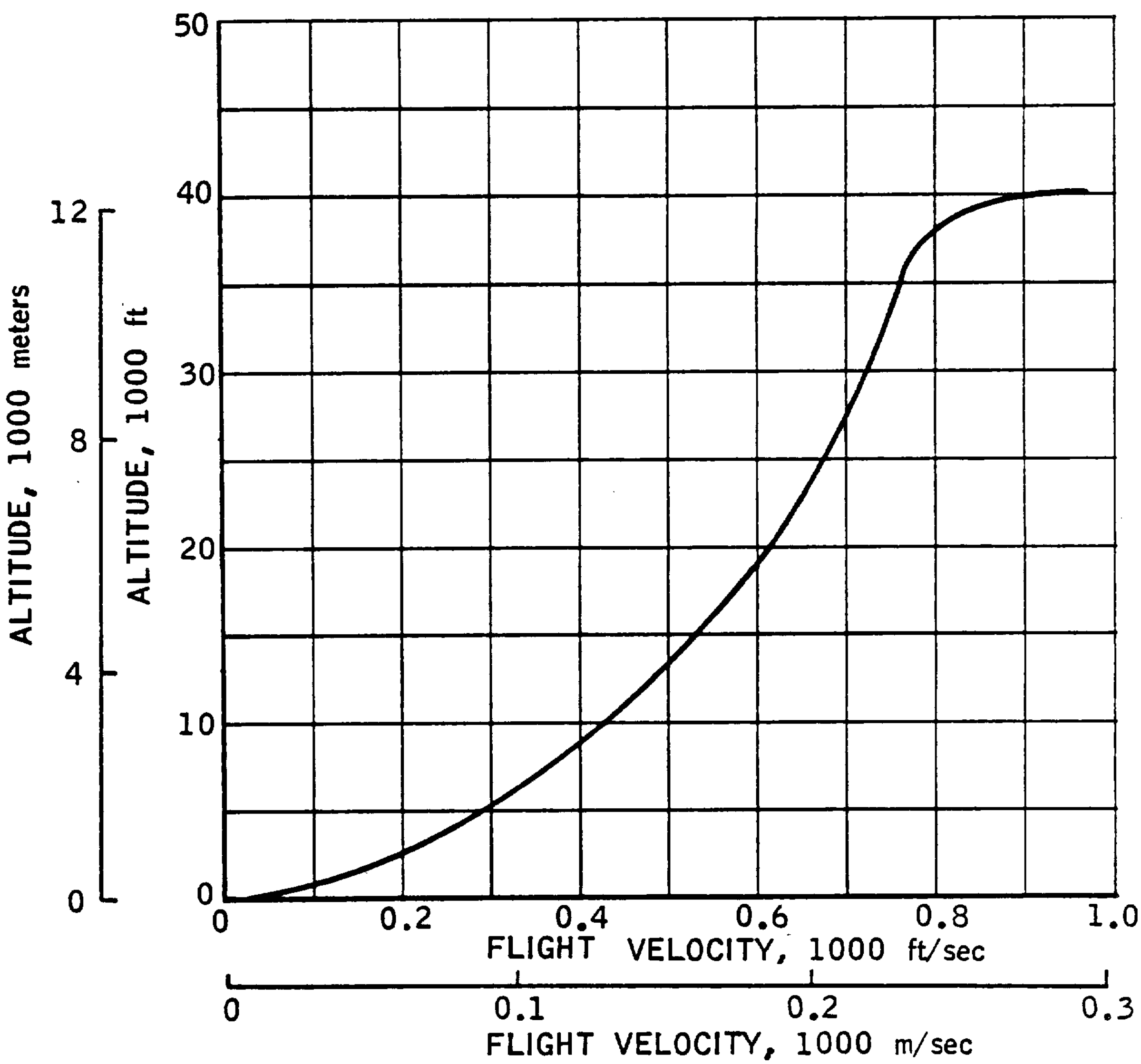
REFERENCE TRAJECTORY SENSITIVITY ANALYSIS



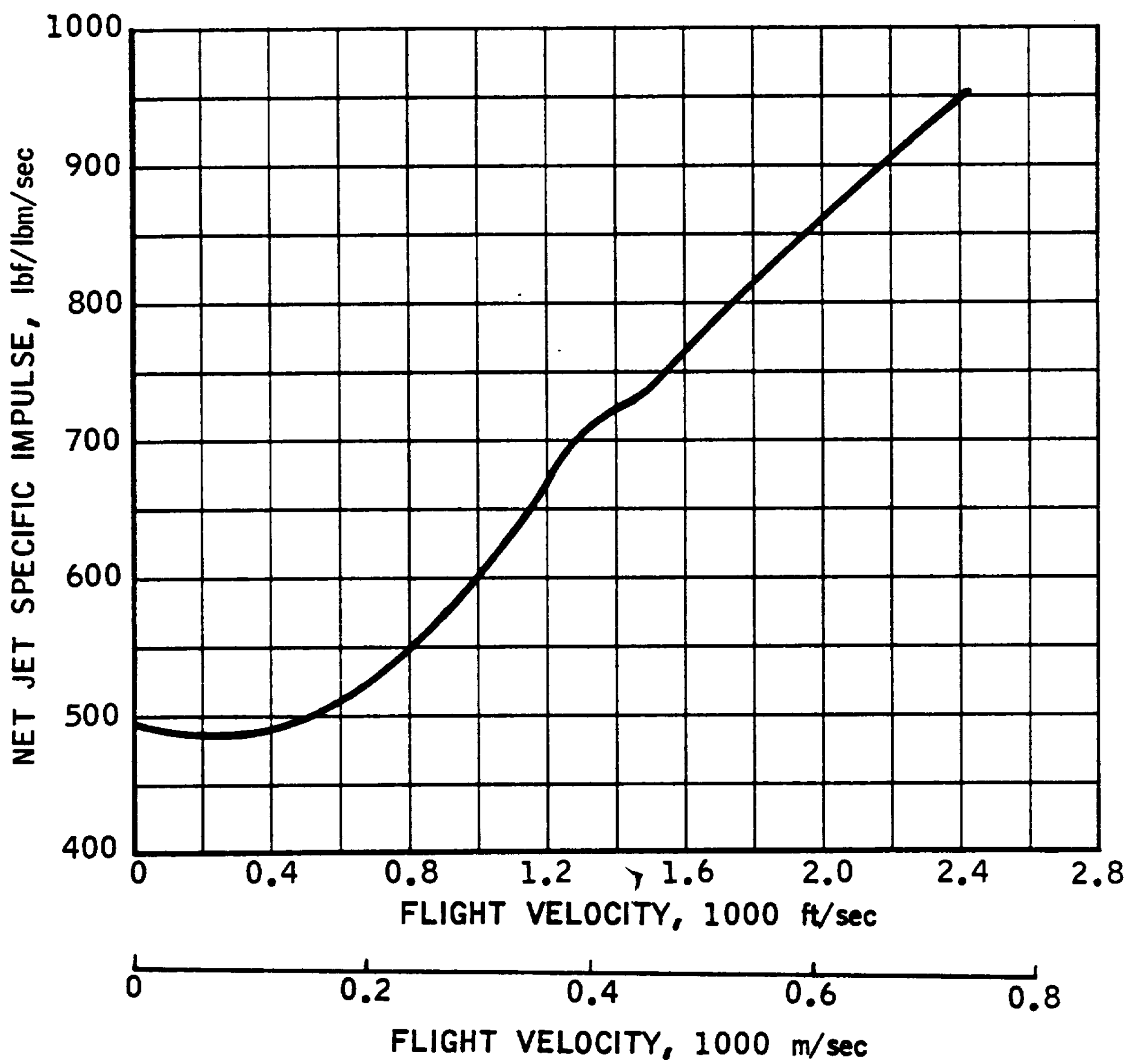
Eng. No. 11

REFERENCE TRAJECTORY SENSITIVITY ANALYSIS

FAN OPERATION ONLY



BASELINE SPECIFIC IMPULSE
EJECTOR MODE



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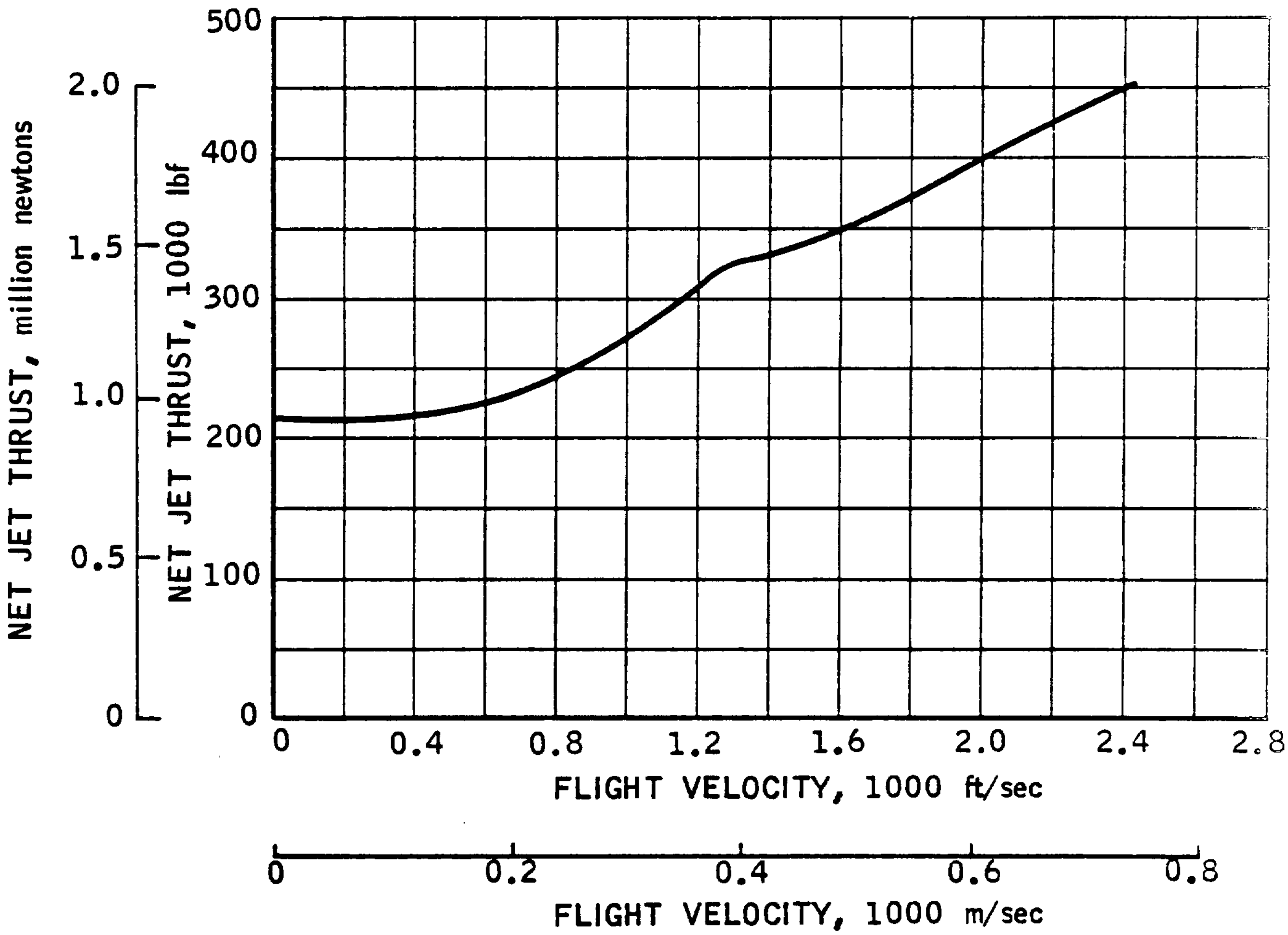
BASELINE THRUST
EJECTOR MODE



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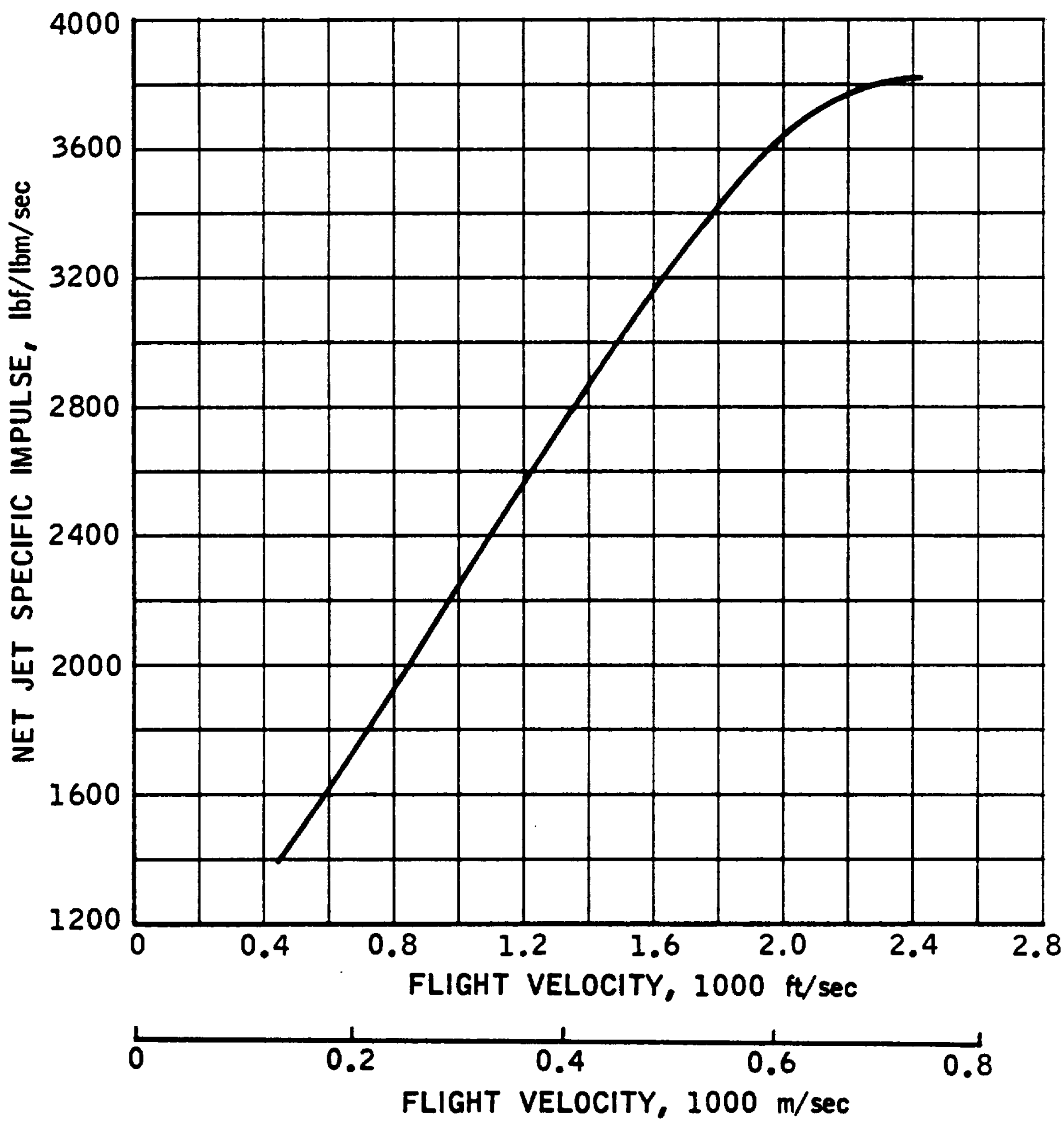
BASELINE SPECIFIC IMPULSE
FAN RAMJET MODE



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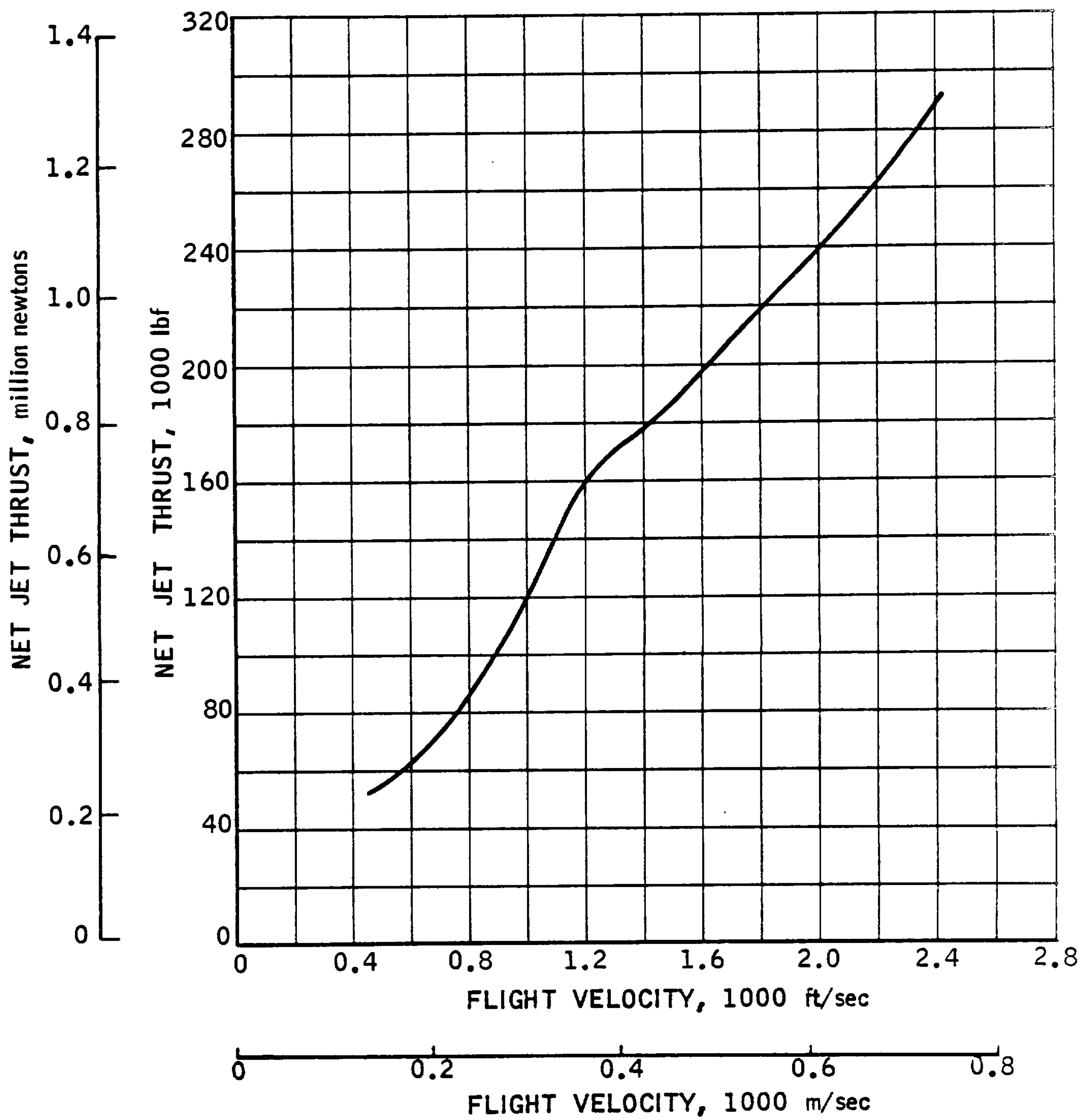
BASELINE THRUST
FAN RAMJET MODE



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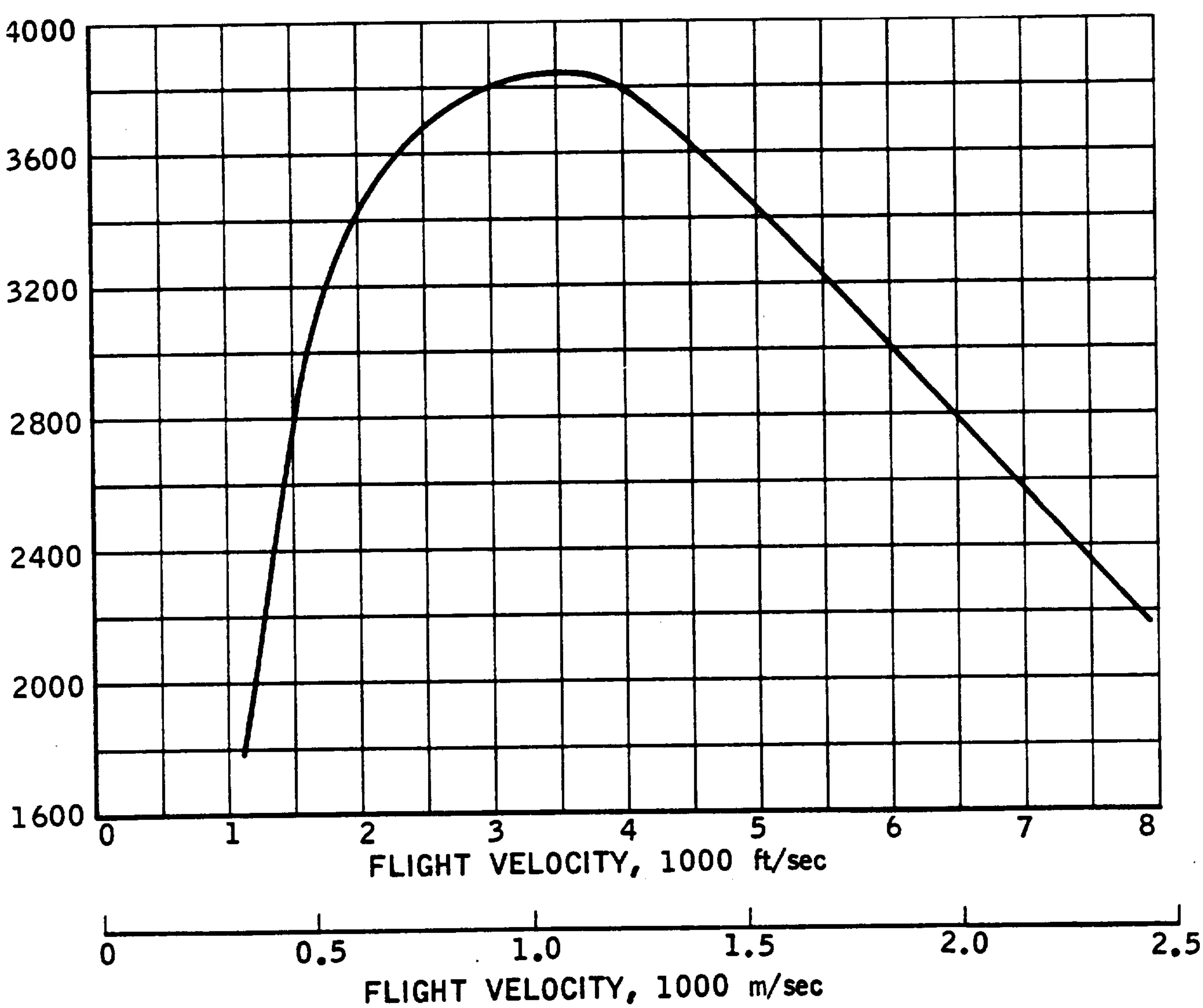
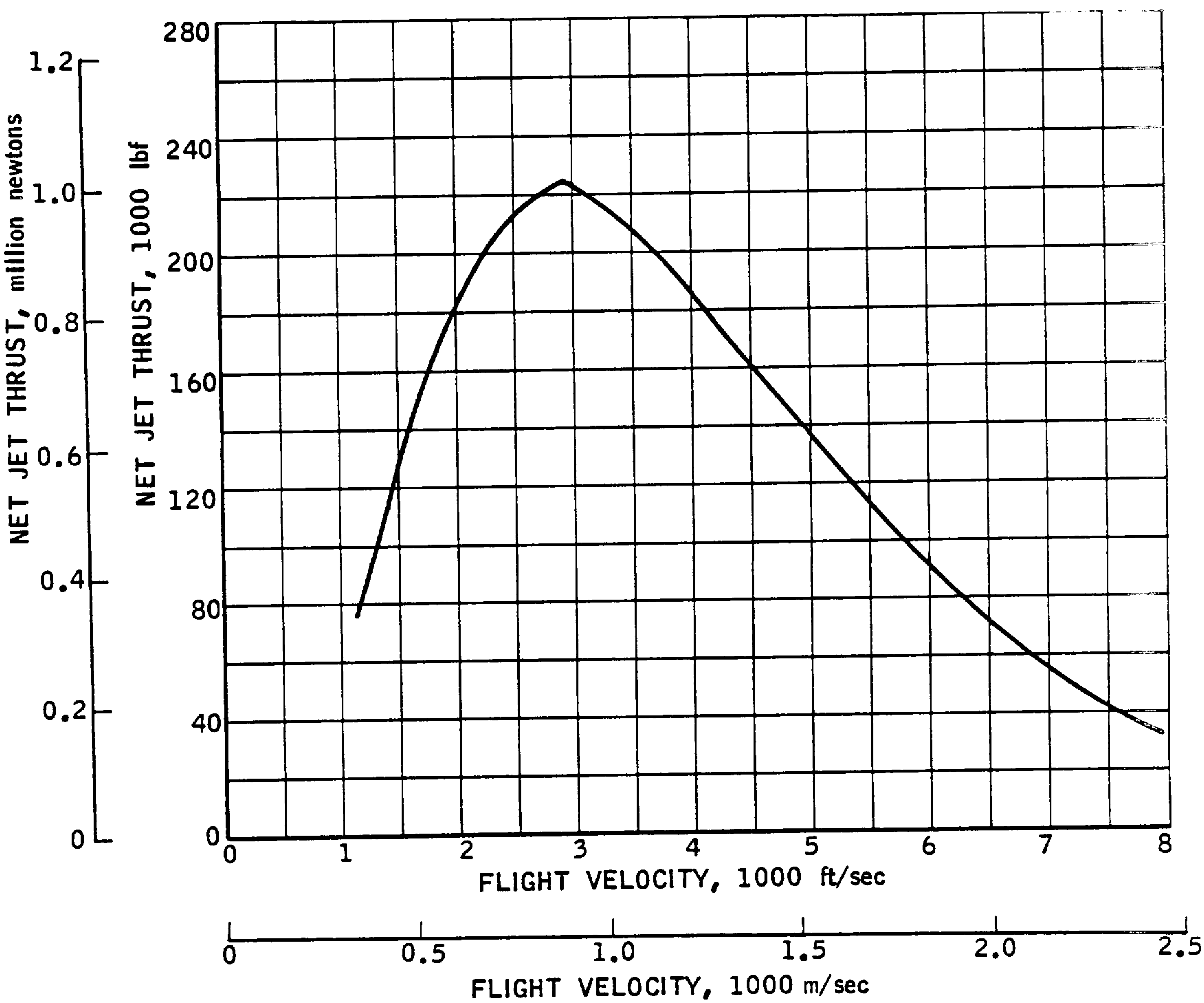
BASELINE SPECIFIC IMPULSE
SUBSONIC COMBUSTION RAMJET



BASELINE THRUST
SUBSONIC COMBUSTION RAMJET



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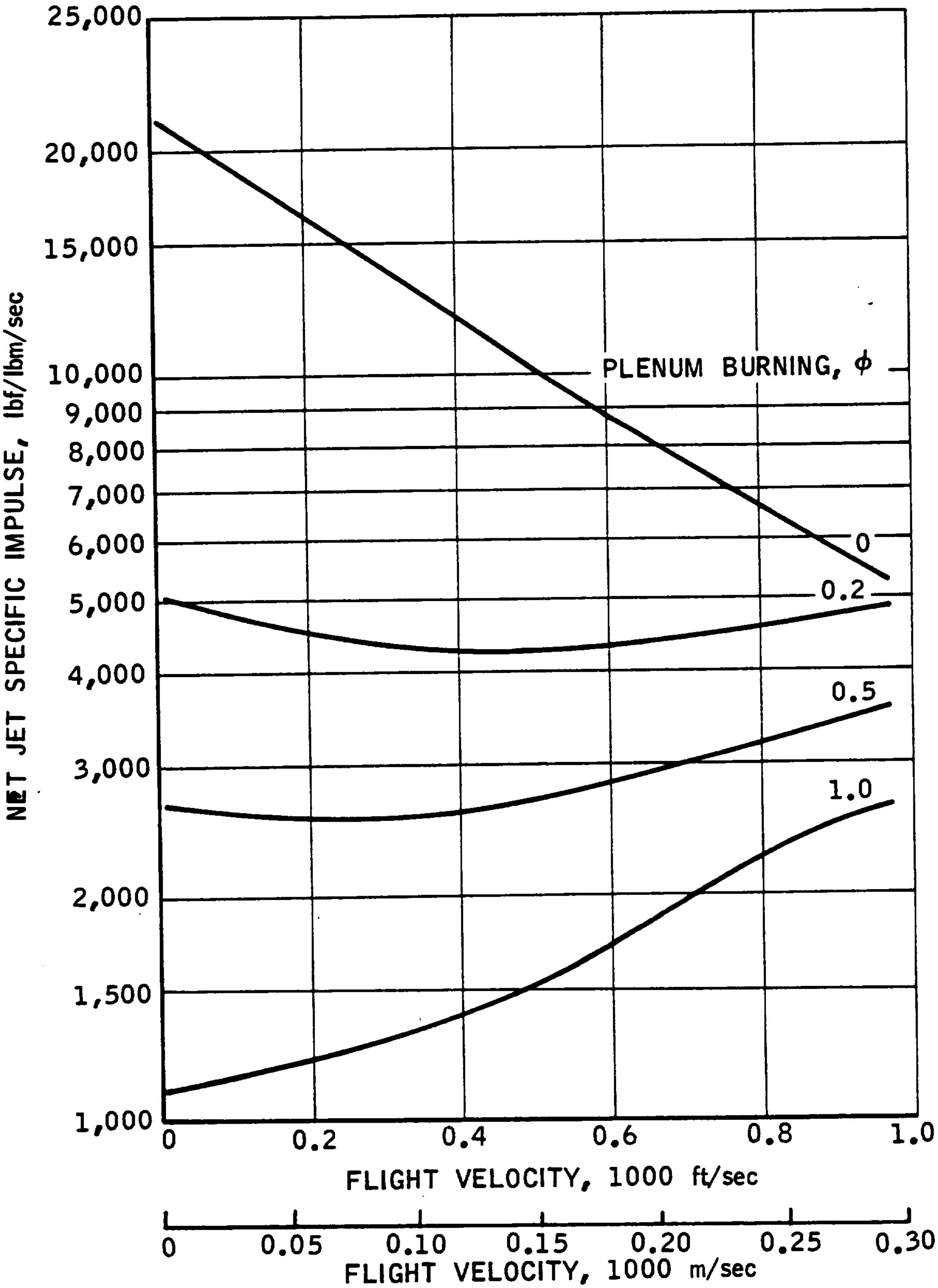
BASELINE SPECIFIC IMPULSE FAN OPERATION



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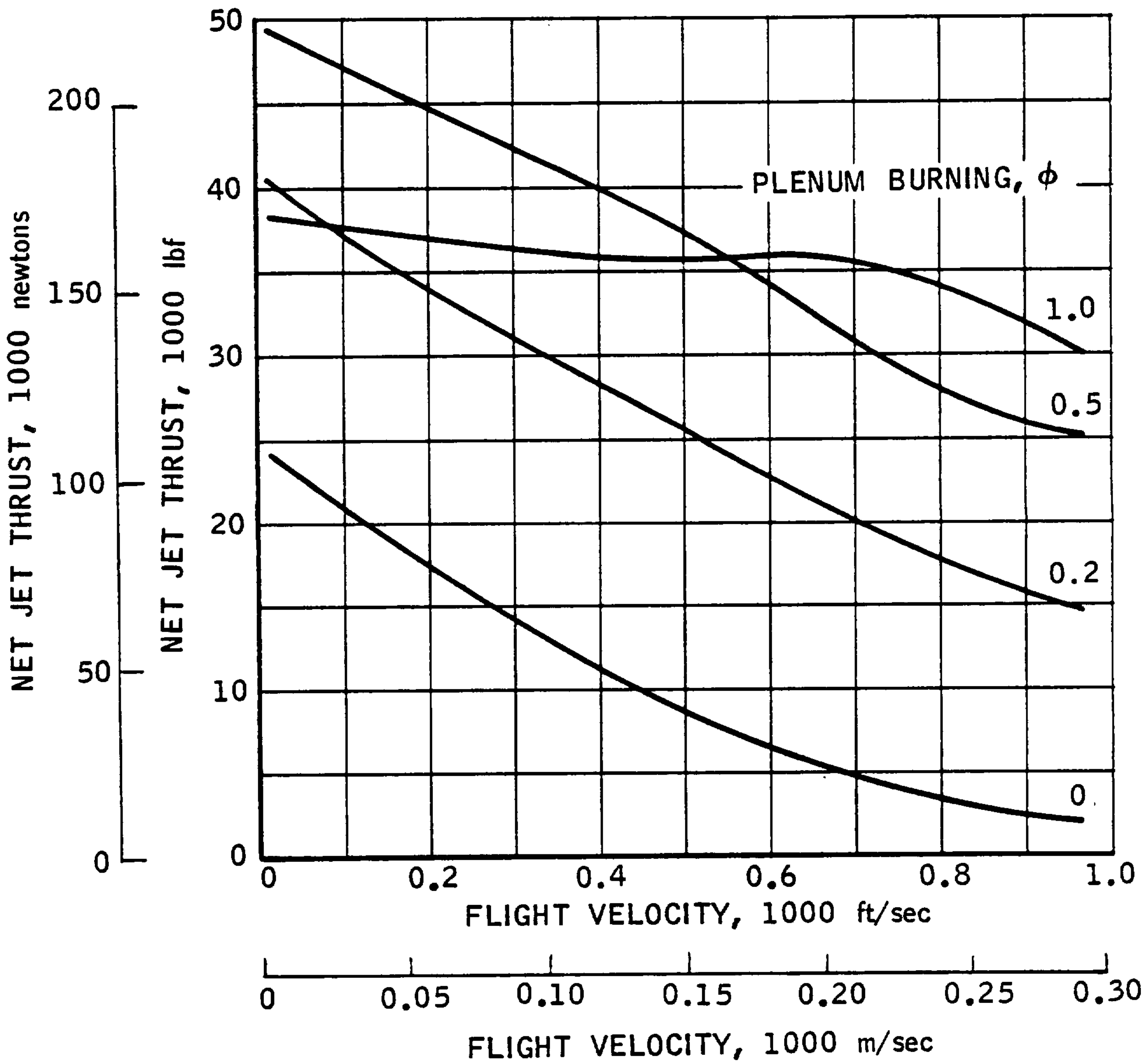
BASELINE THRUST
FAN OPERATION



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SENSITIVITY ANALYSIS RANGES

	Base-line	Range	
Ejector Mode:			
Inlet - Pressure recovery, P_{t_2}/P_{t_o}	Figure A		
Fan - Pressure ratio, PR_f	1.30	1.50	1.10
Primary			
Equivalence ratio, ϕ	1.00	1.10	0.90
Combustion efficiency, η_{c^*}	0.975	1.00	0.92
Nozzle efficiency, η_N	0.98	1.00	0.95
Mixer - Mixing efficiency, η_M	0.80	1.00	0.50
Afterburner			
Equivalence ratio, ϕ_{AB}	1.00	1.50	0.50
Combustion efficiency, η_c	0.95	1.00	0.85
Exit			
Nozzle efficiency, η_N	0.98	1.00	0.95
Exit area ratio, A_6/A_5	Figure B		
Fan Ramjet Mode:			
Inlet - Pressure recovery, P_{t_2}/P_{t_o}	Figure A		
Fan - Pressure ratio, PR_f	1.30	1.50	1.10
Afterburner			
Equivalence ratio, ϕ_{AB}	1.00	1.50	0.50
Combustion efficiency, η_c	0.95	1.00	0.85
Exit			
Nozzle efficiency, η_N	0.98	1.00	0.95
Exit area ratio, A_6/A_5	Figure C		
Subsonic Combustion Ramjet:			
Inlet - Pressure recovery, P_{t_2}/P_{t_o}	Figure A		
Combustor			
Equivalence ratio, ϕ	1.00	1.50	0.50
Combustion efficiency, η_c	0.95	1.00	0.85
Exit			
Nozzle efficiency, η_N	0.98	1.00	0.95
Exit area ratio, A_6/A_5	Figure D		
Fan Operation:			
Inlet - Pressure recovery, P_{t_2}/P_{t_o}	1.00	0.95	0.90
Fan - Pressure ratio, PR_f	1.30	1.50	1.10
Afterburner - Combustion efficiency, η_c	0.95	1.00	0.85
Exit - Nozzle Efficiency, η_N	0.98	1.00	0.95

Figure A INLET PRESSURE RECOVERY SENSITIVITY ANALYSIS RANGE

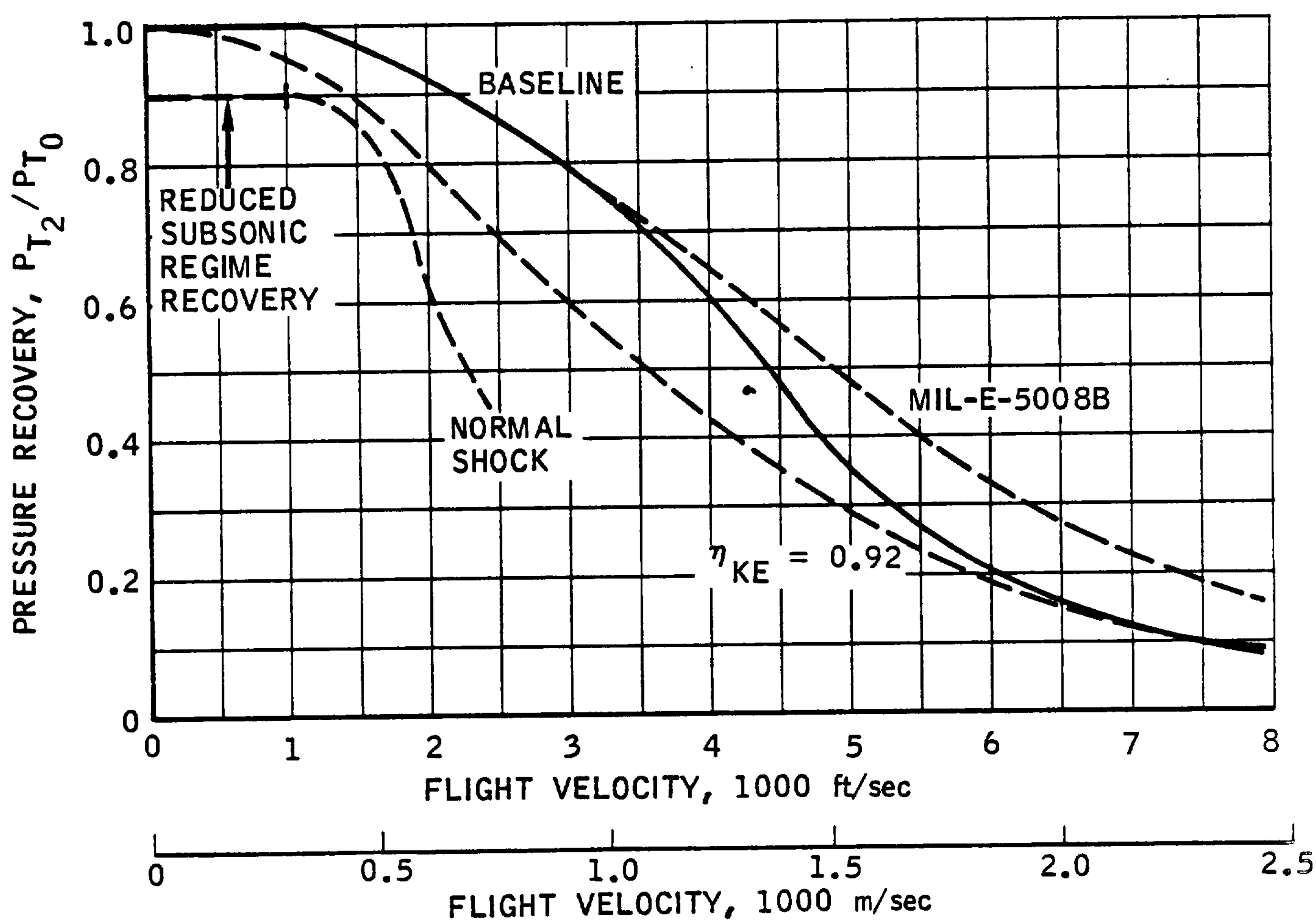


Figure B

EXIT NOZZLE AREA RATIO SENSITIVITY ANALYSIS RANGE

EJECTOR MODE

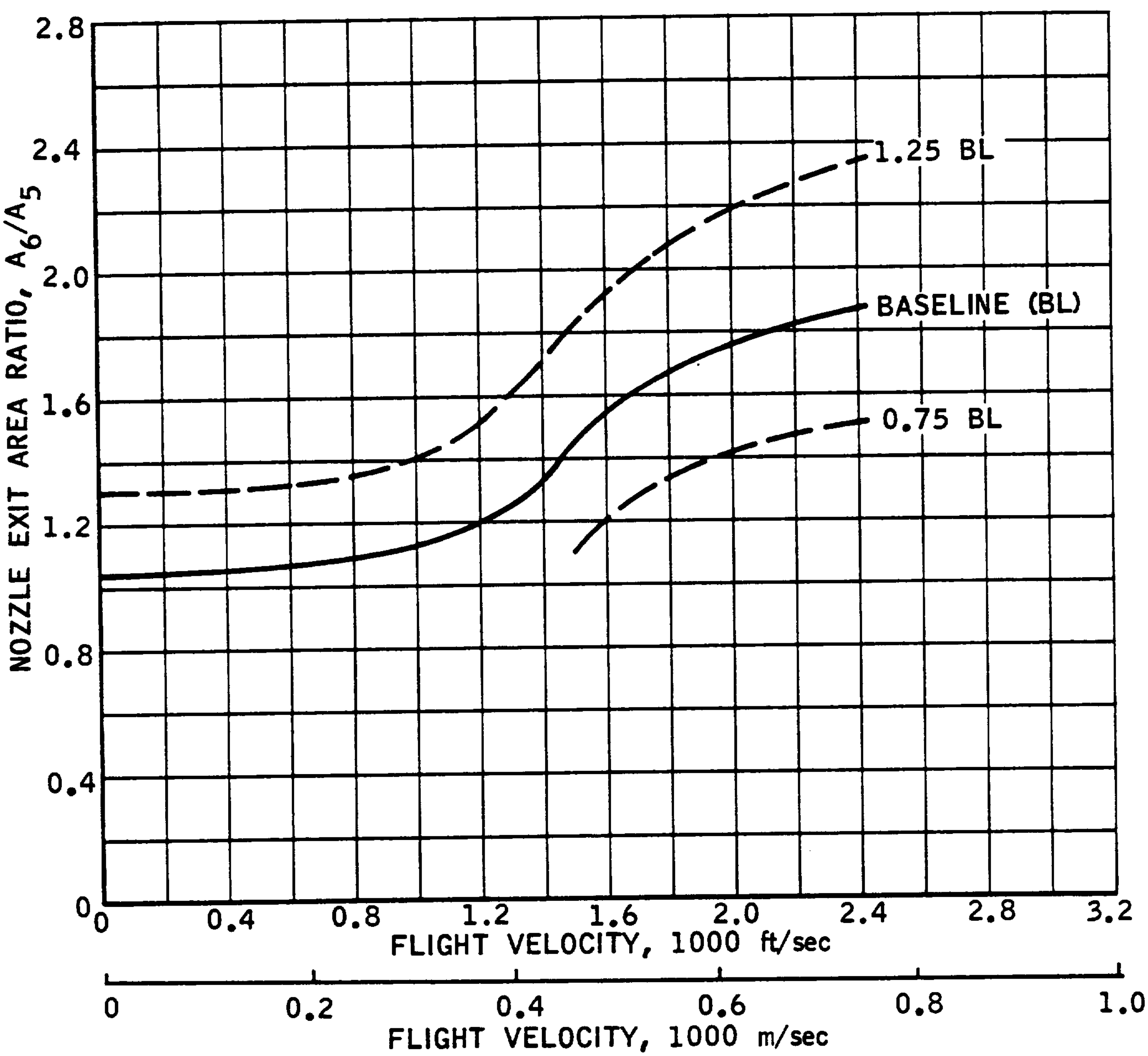


FIGURE C EXIT NOZZLE AREA RATIO SENSITIVITY ANALYSIS RANGE

FAN RAMJET MODE

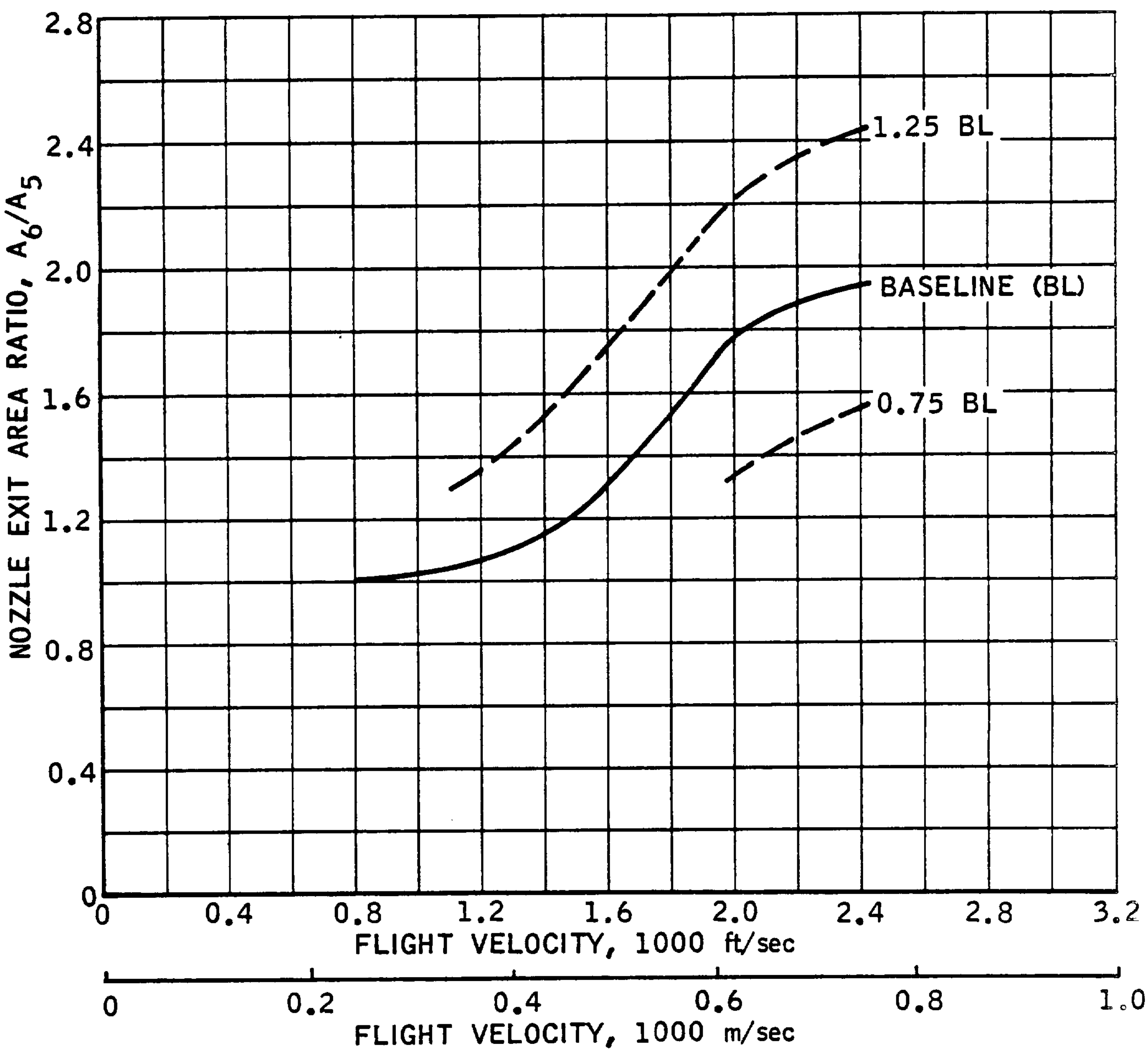
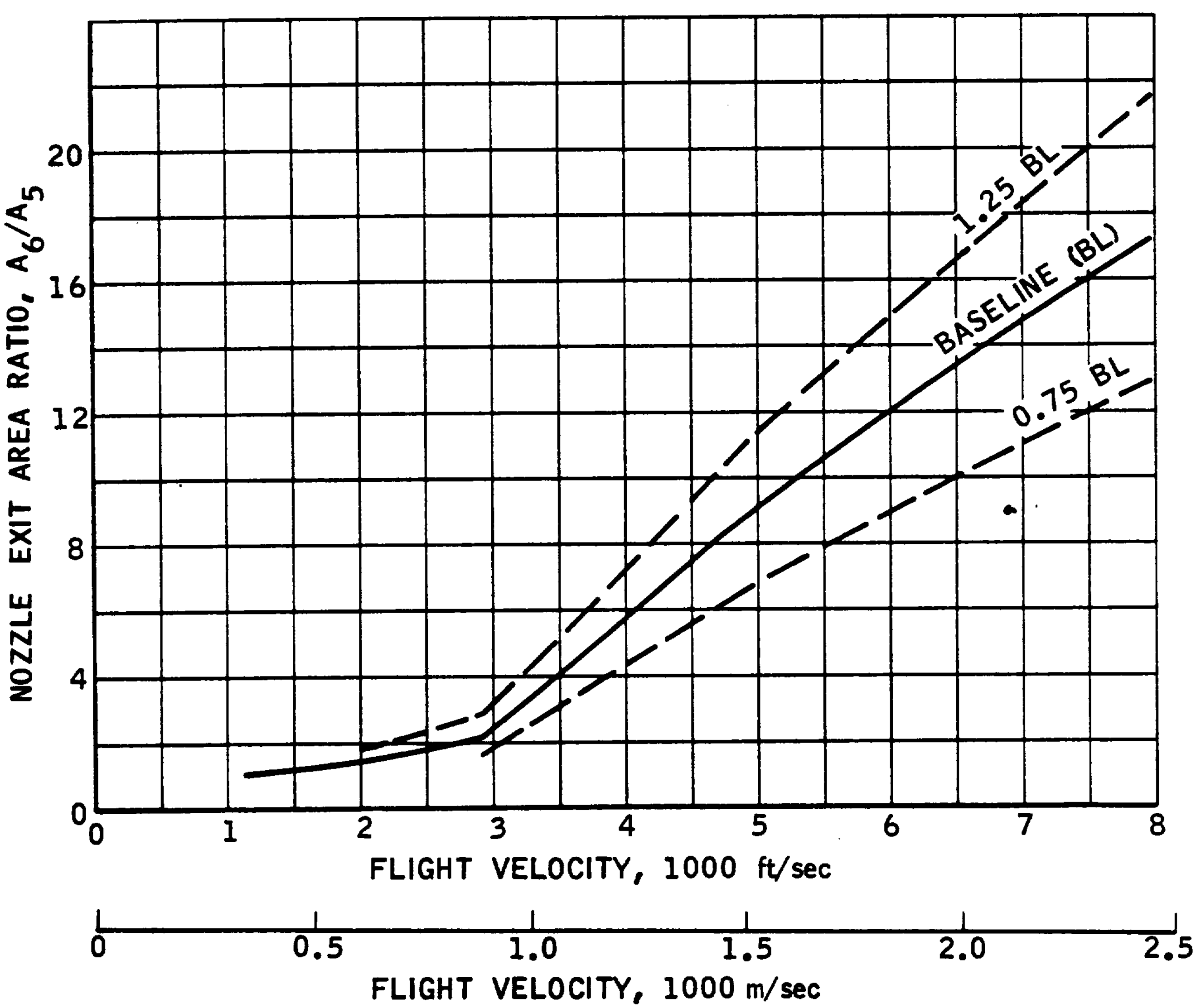


Figure D EXIT NOZZLE AREA RATIO SENSITIVITY ANALYSIS RANGE

SUBSONIC COMBUSTION RAMJET



SENSITIVITY ANALYSIS - RESULTS

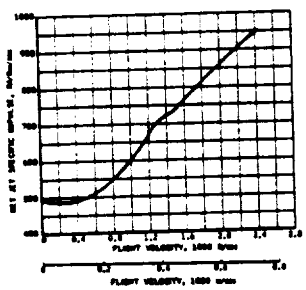
For the reference conditions stated in the previous section, resulting specific impulse and thrust perturbations are presented here. Performance is normalized to the baseline trends given over the appropriate flight velocity ranges.

The specific impulse and thrust data are both displayed on individual sheets for each sensitivity variable. On the same sheet, a miniature plot of the absolute specific impulse and thrust baseline characteristic is shown for nominal reference purposes. For precise readings, the full-sized curve appearing previously (its page number is indicated) should be referred to.

The section concludes with a plot reflecting subsystem weight variations on uninstalled engine thrust/weight ratio.

INLET PRESSURE RECOVERY EFFECT
EJECTOR MODE

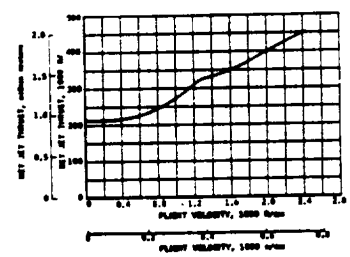
Page 60 — BASELINE SPECIFIC IMPULSE EJECTOR MODE

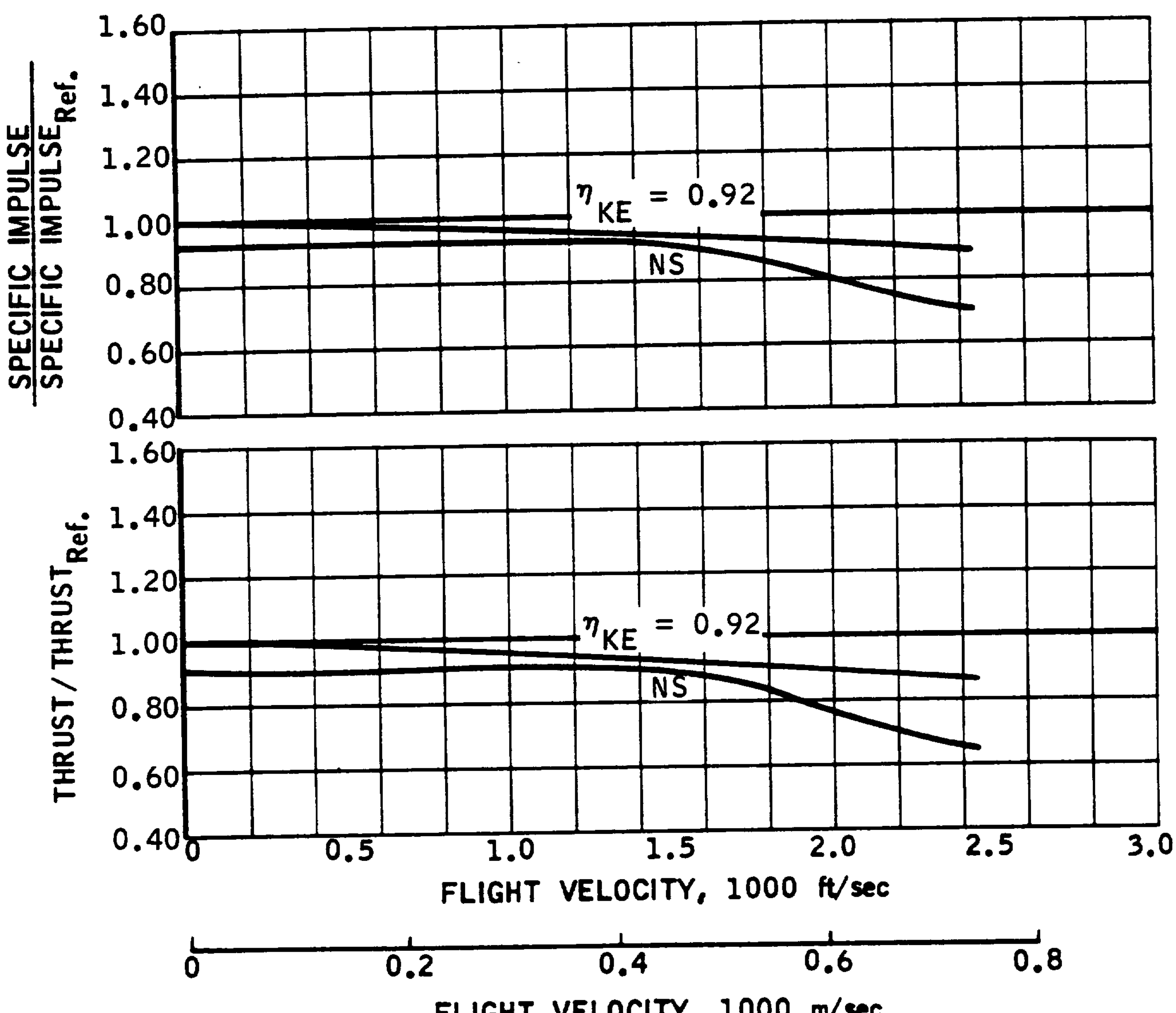


Eng. No. 11

Baseline
P_{T_2}/P_{T_0}:
Figure A
(Page 69)

Page 61 — BASELINE THRUST EJECTOR MODE

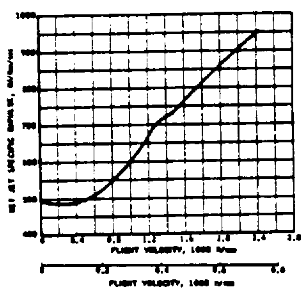




[redacted]

FAN PRESSURE RATIO EFFECT
EJECTOR MODE

Page 60

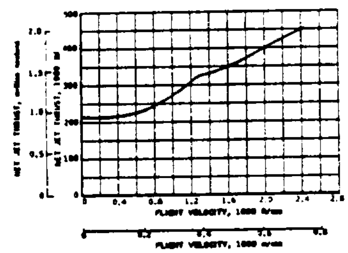


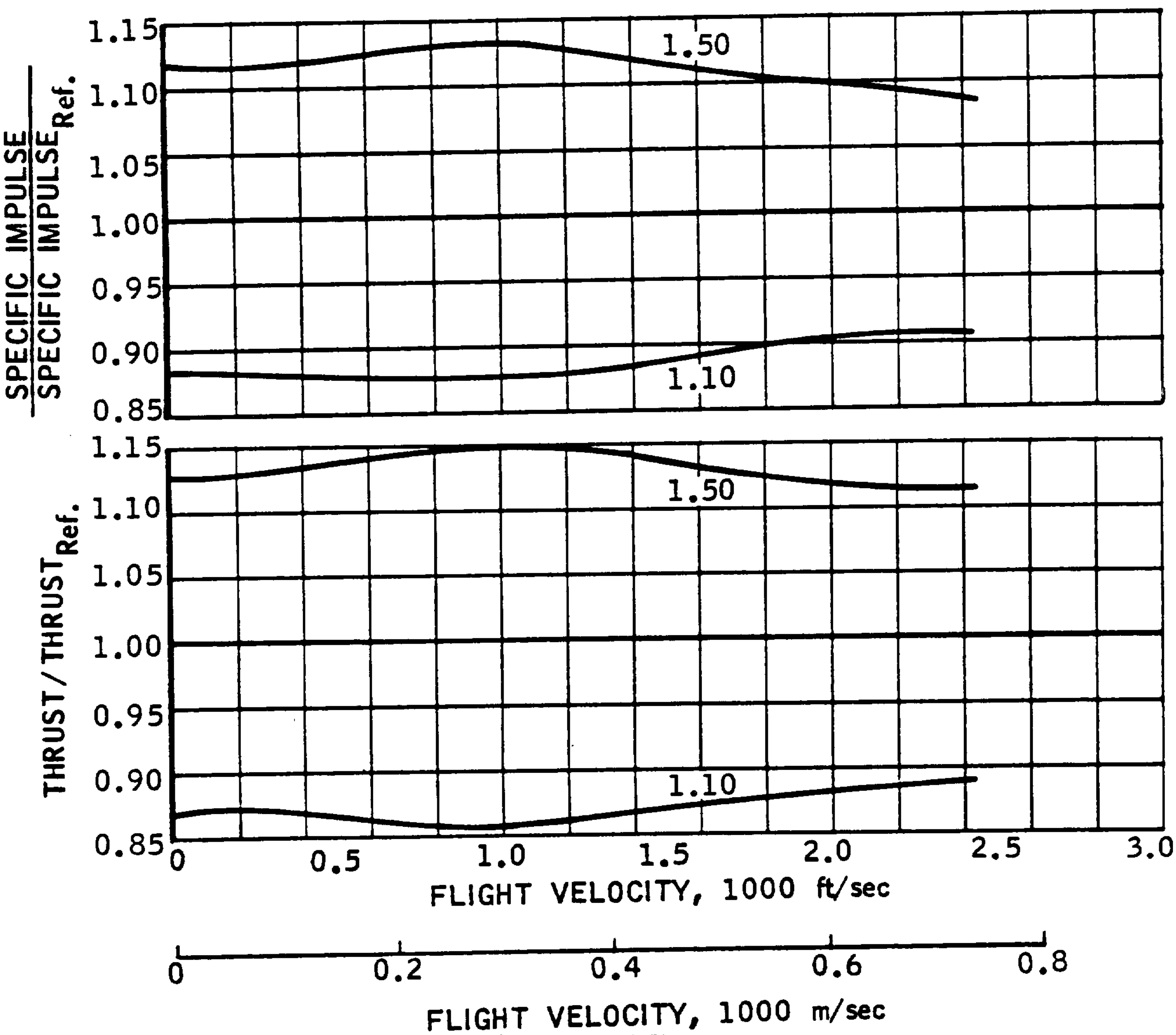
Eng. No. 11

Baseline

$PR_f = 1.30$

Page 61

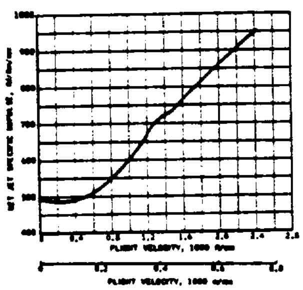




PRIMARY ROCKET EQUIVALENCE RATIO EFFECT

EJECTOR MODE

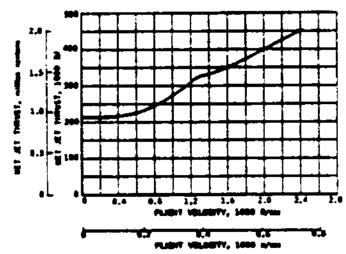
Page 60

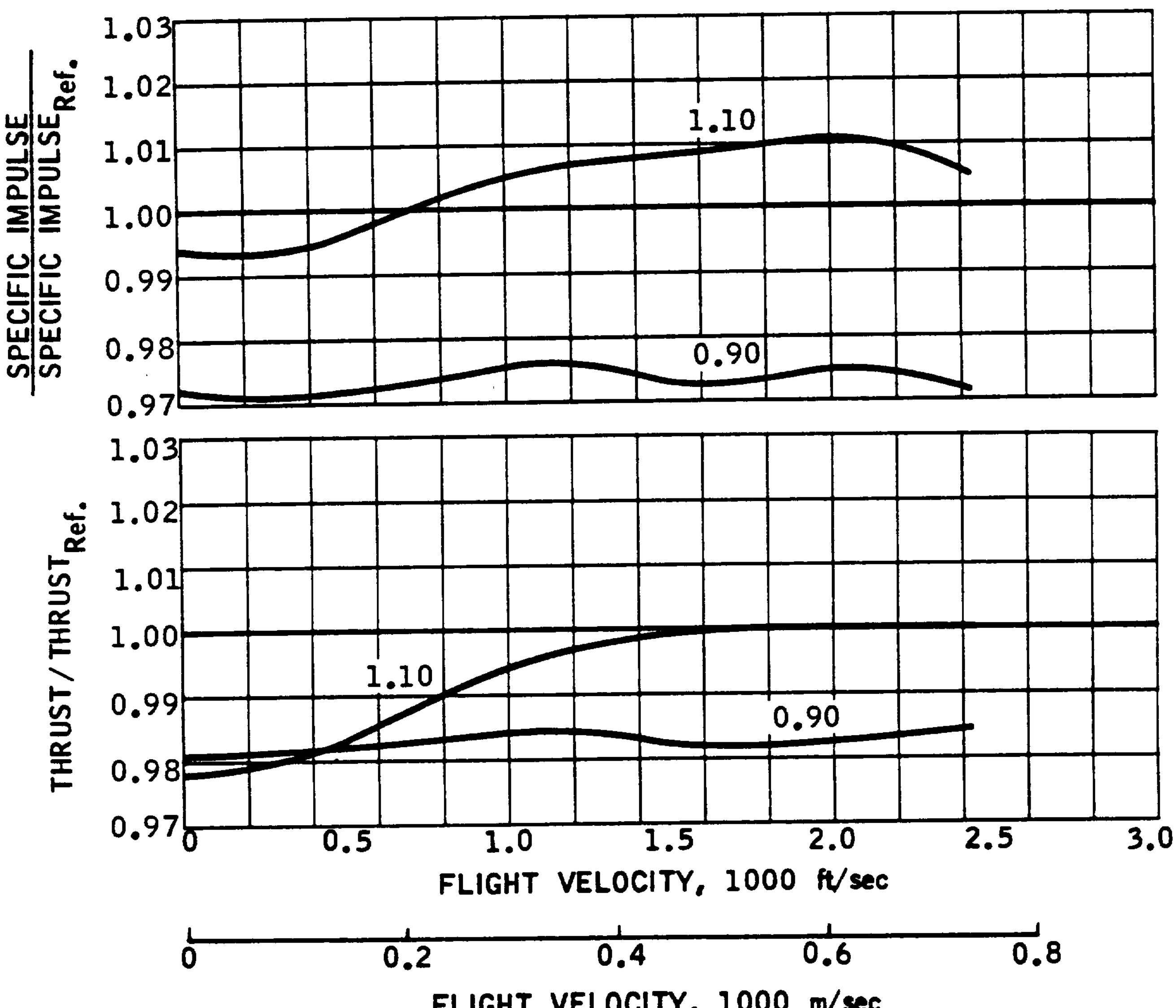


Eng. No. 11

Baseline
$\phi = 1.00$

Page 61

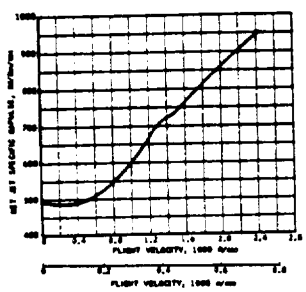




PRIMARY ROCKET COMBUSTION EFFICIENCY EFFECT
EJECTOR MODE

Page 60

BASELINE SPECIFIC IMPULSE EJECTOR MODE



Eng. No. 11

Baseline

$\eta_c^* = 0.975$

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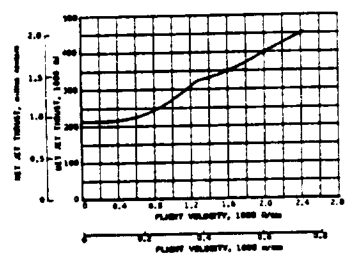
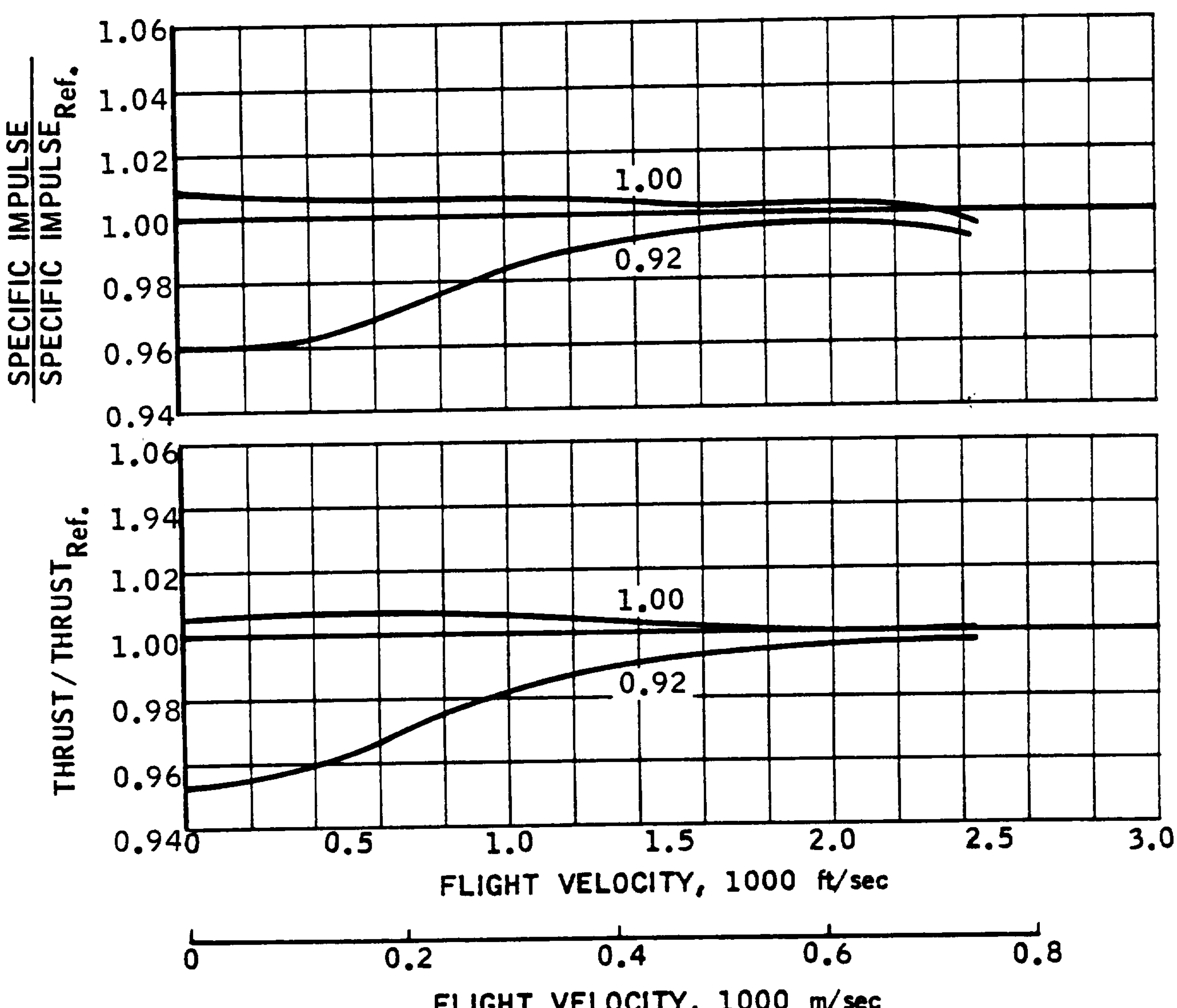
BASELINE THRUST EJECTOR MODE





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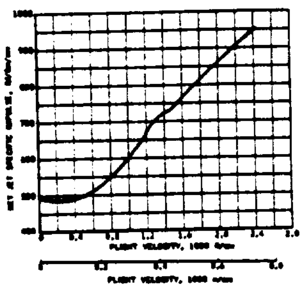
PRIMARY ROCKET NOZZLE EFFICIENCY EFFECT
EJECTOR MODE

Page 60

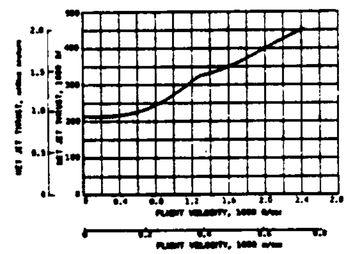


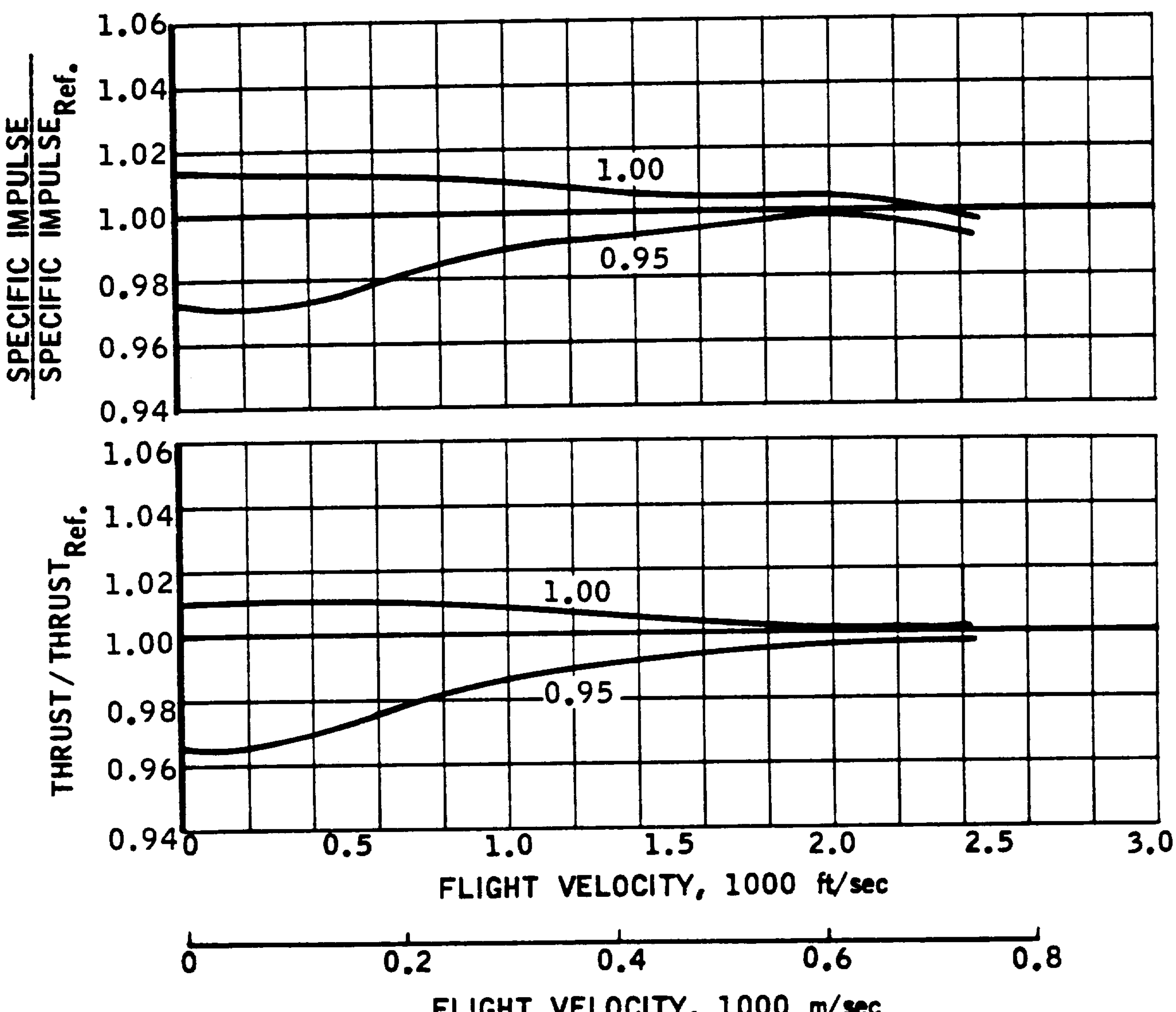
Eng. No. 11

Baseline

$\eta_N = 0.98$

Page 61

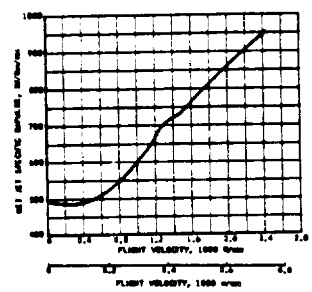




[redacted]

MIXING EFFICIENCY EFFECT
EJECTOR MODE

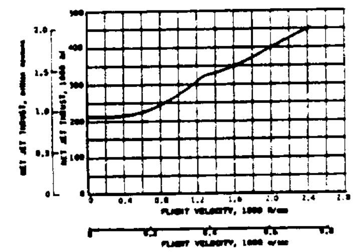
Page 60
BASELINE SPECIFIC IMPULSE EJECTOR MODE

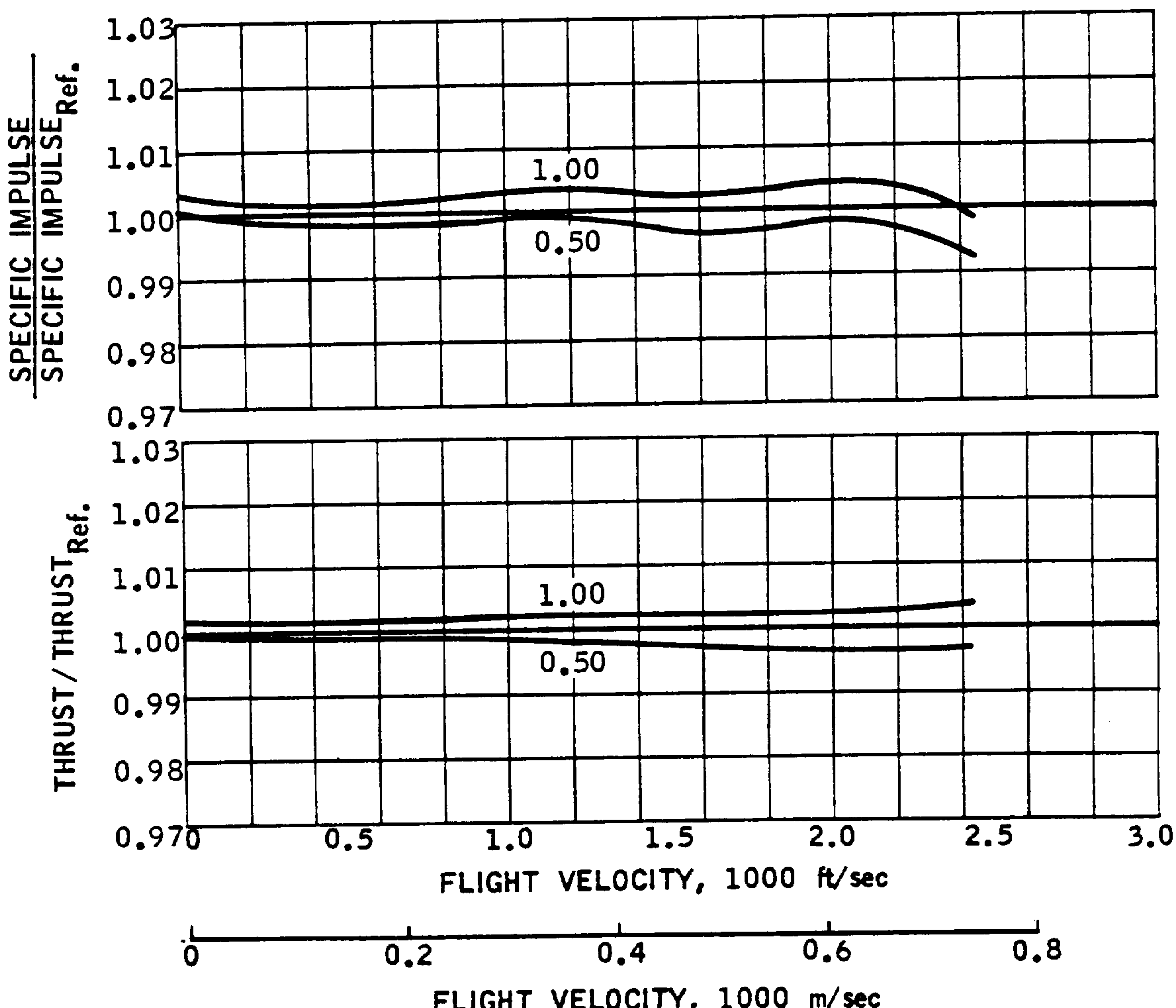


Eng. No. 11

Baseline
$\eta_M = 0.80$

Page 61
BASELINE THRUST EJECTOR MODE





[redacted]

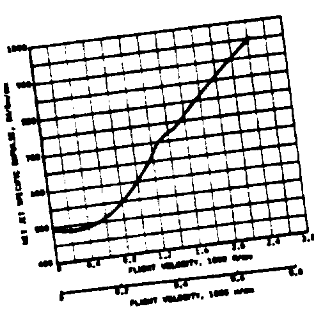
[redacted]

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

AFTERBURNER EQUIVALENCE RATIO EFFECT
EJECTOR MODE

Page 60

BASELINE SPECIFIC IMPULSE EJECTOR MODE



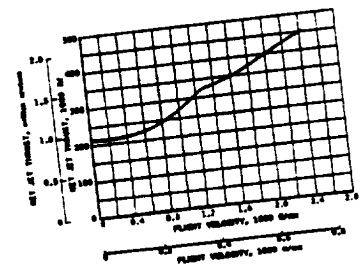
Eng. No. 11

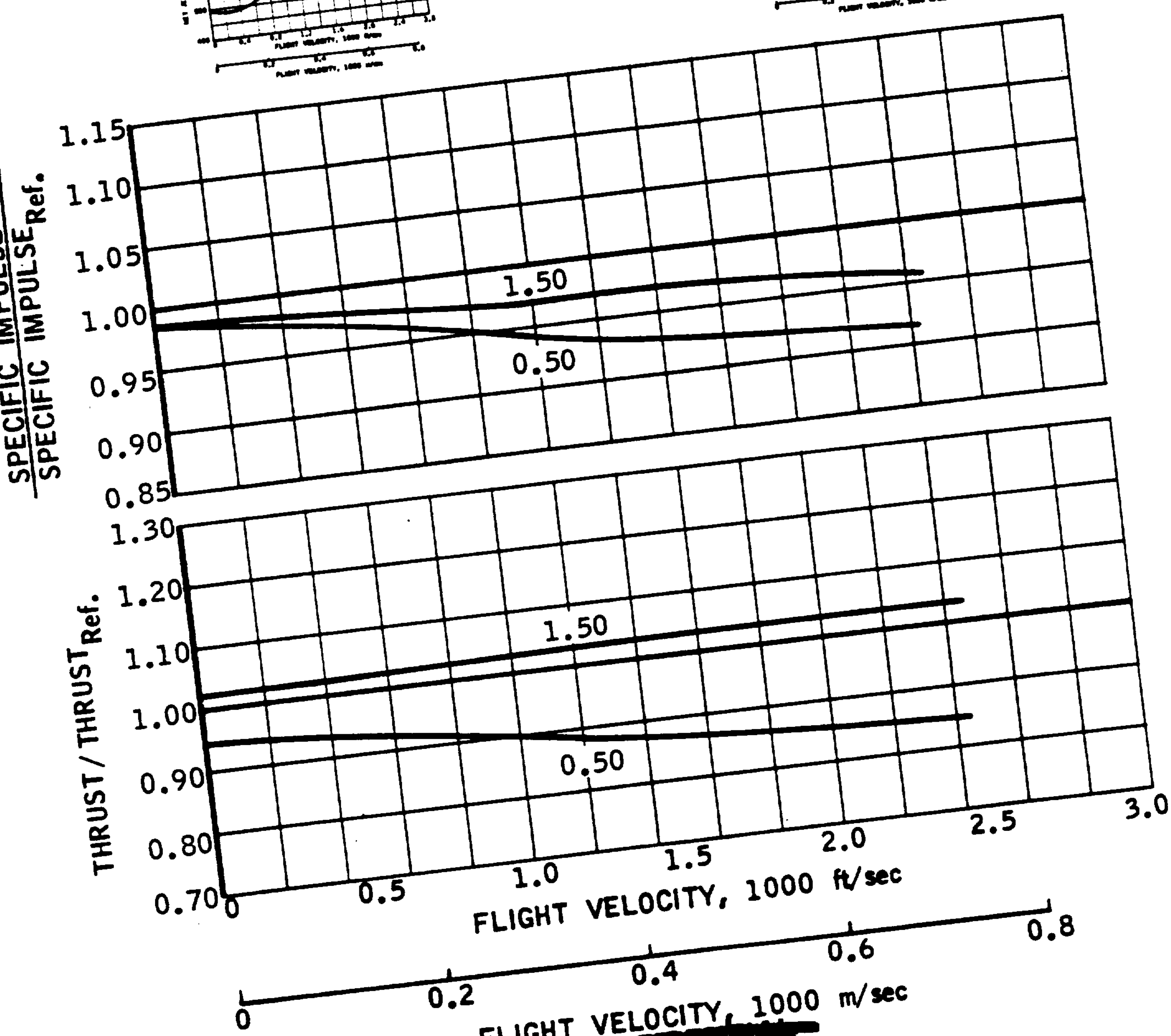
Baseline

$\phi_{AB} = 1.00$

Page 61

BASELINE THRUST EJECTOR MODE



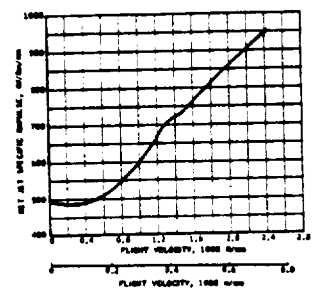


[redacted]

AFTERBURNER COMBUSTION EFFICIENCY EFFECT EJECTOR MODE

Page 60

BASELINE SPECIFIC IMPULSE EJECTOR MODE



Eng. No. 11

Baseline

$\eta_c = 0.95$

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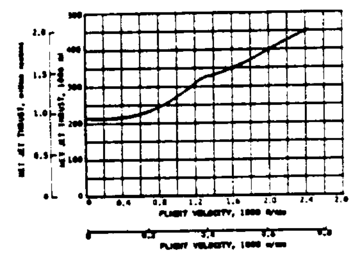
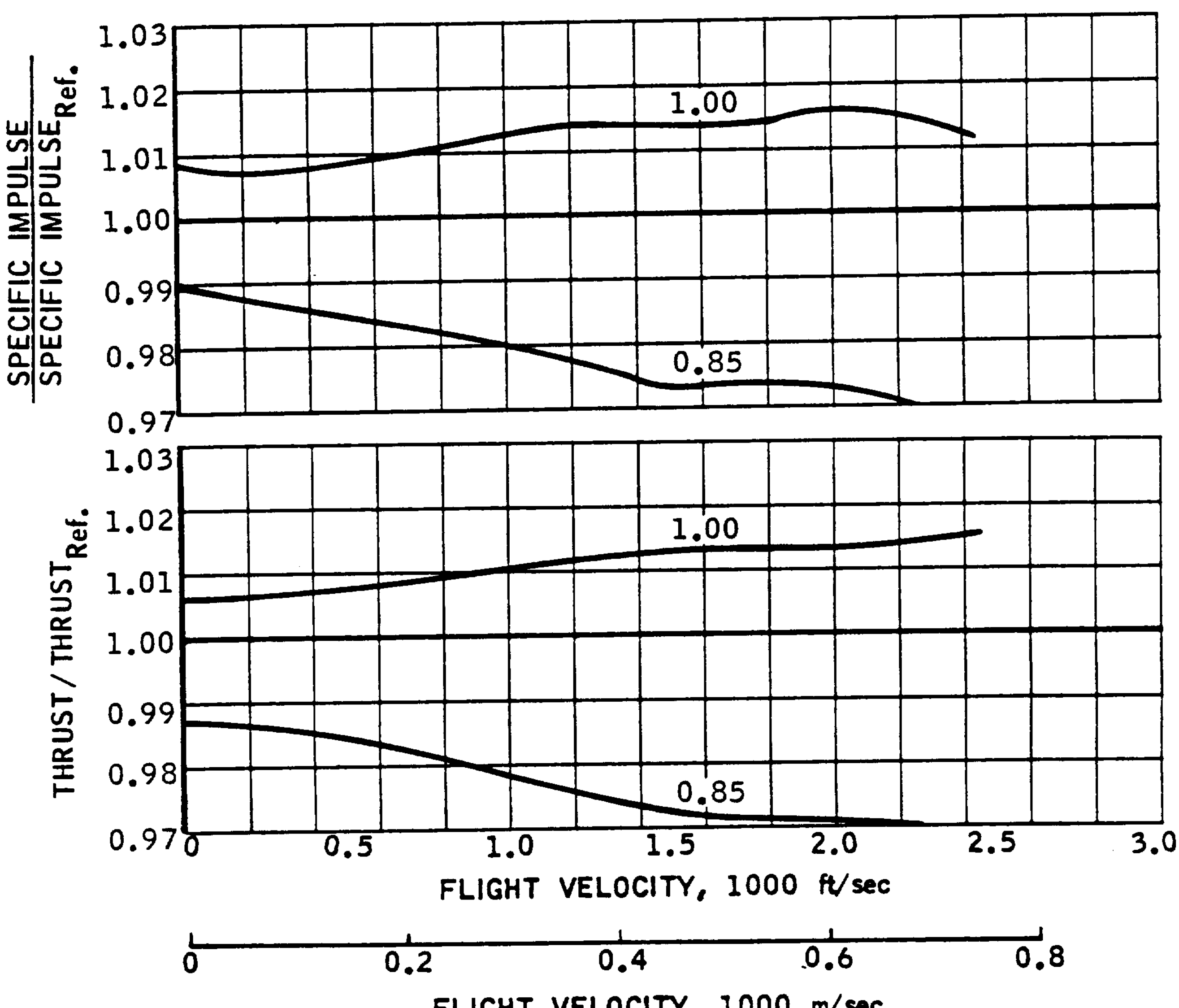
BASELINE THRUST EJECTOR MODE





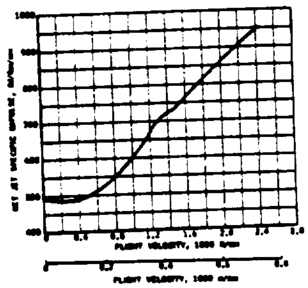
[redacted]

EXIT NOZZLE EFFICIENCY EFFECT
EJECTOR MODE

Eng. No. 11

Page 60

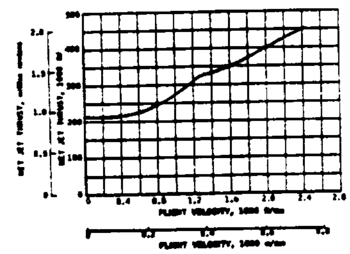
BASELINE SPECIFIC IMPULSE EJECTOR MODE

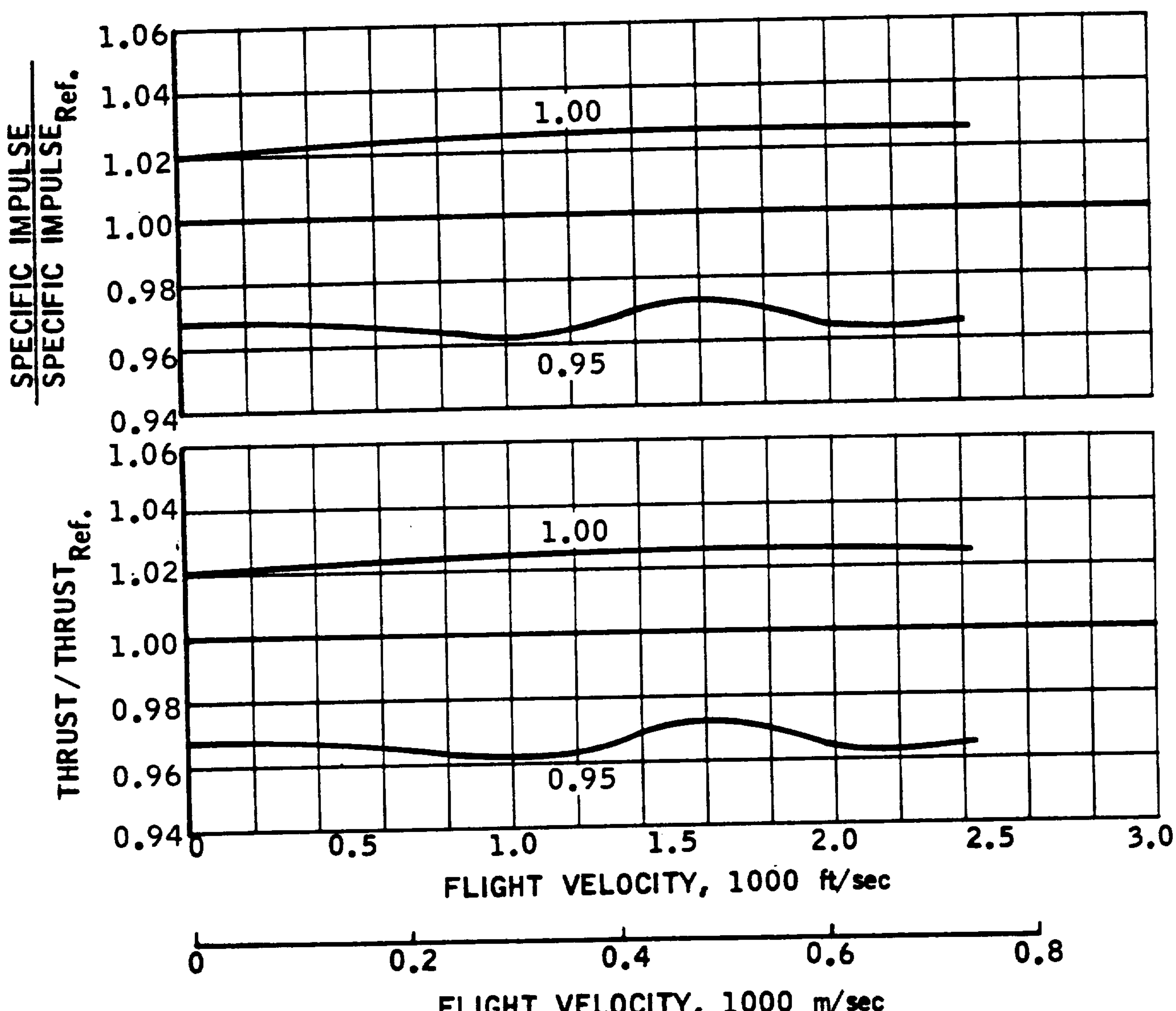


Baseline
$\eta_N = 0.98$

Page 61

BASELINE THRUST EJECTOR MODE





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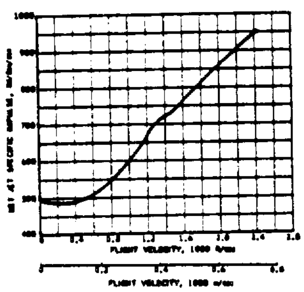
EXIT NOZZLE AREA RATIO EFFECT
EJECTOR MODE

Eng. No. 11

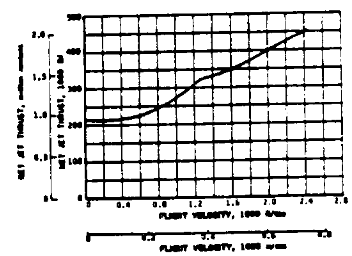
Page 60

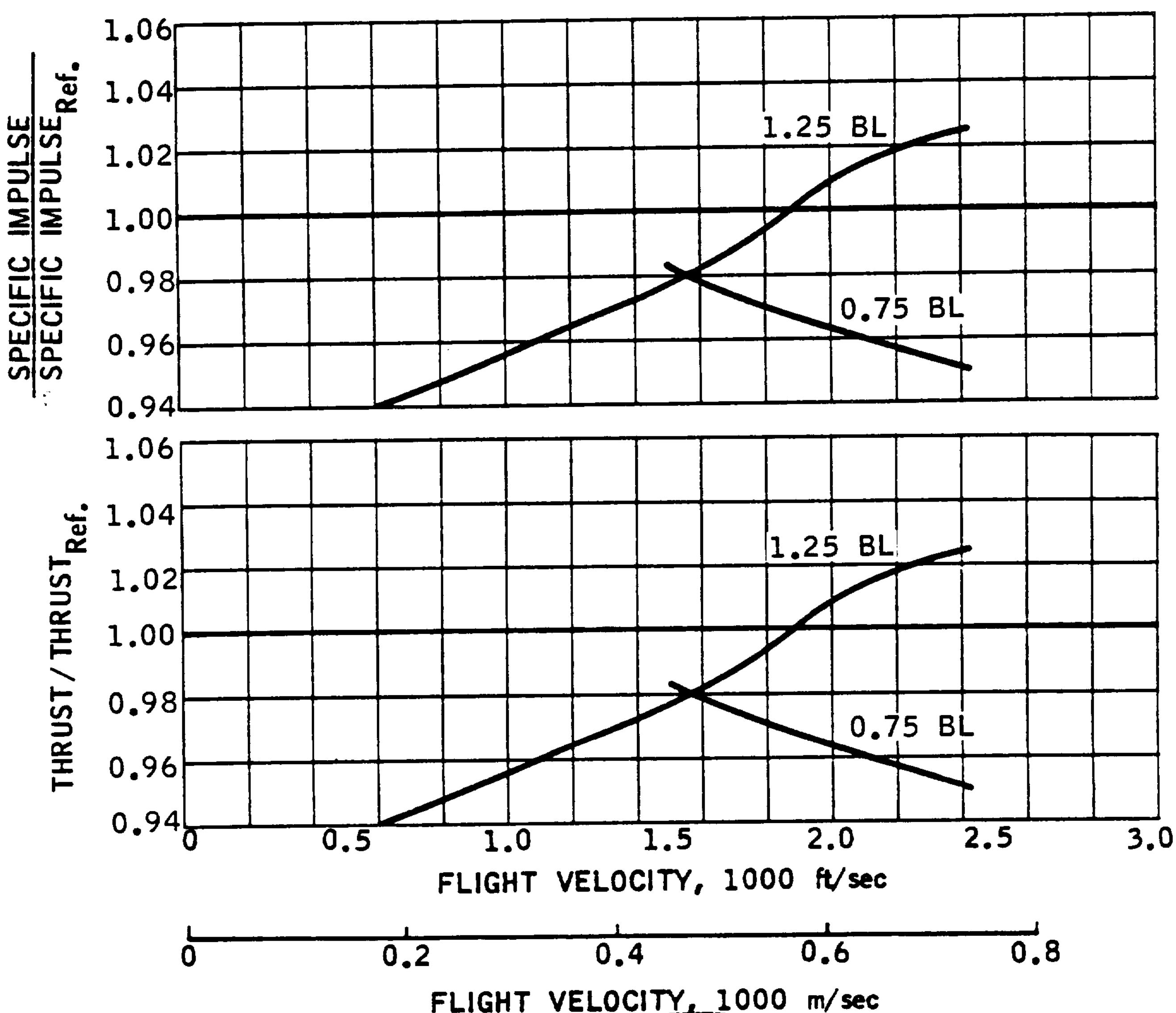


Baseline

A_6/A_5:
Figure B
(Page 70)

Page 61





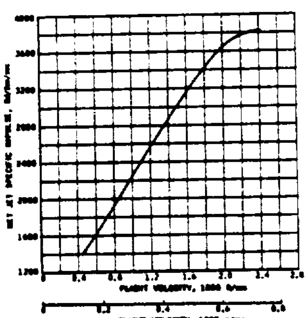
[redacted]

INLET PRESSURE RECOVERY EFFECT

FAN RAMJET MODE

Page 62

BASELINE SPECIFIC IMPULSE FAN RAMJET MODE



Eng. No. 11

Baseline P_{T_2}/P_{T_0}:
Figure A
(Page 69)

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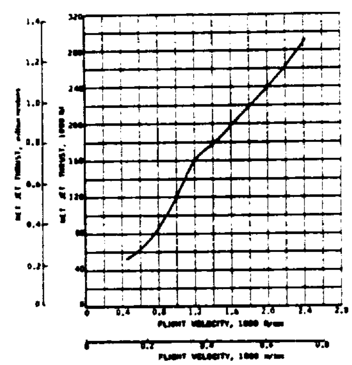
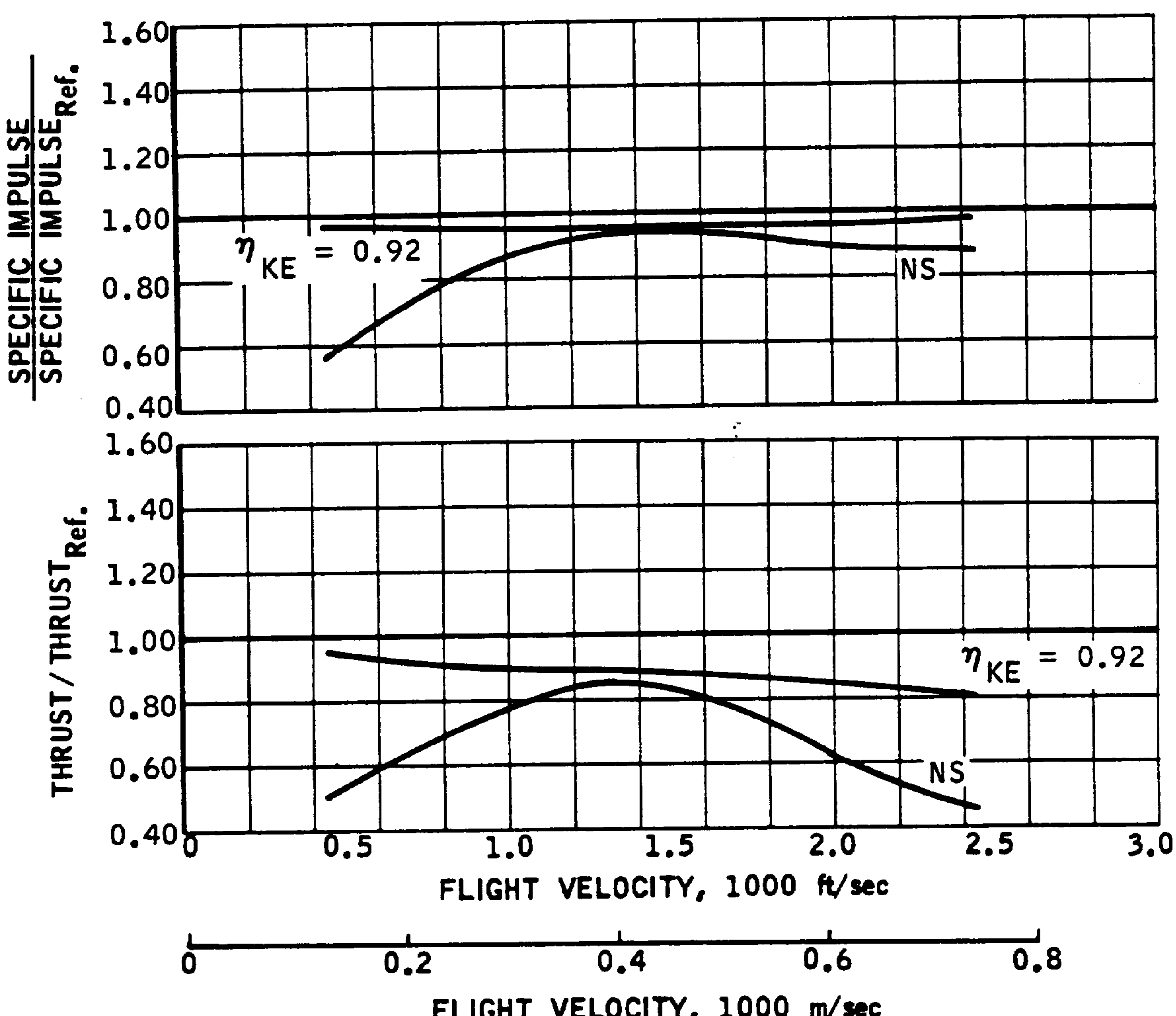
BASELINE THRUST FAN RAMJET MODE





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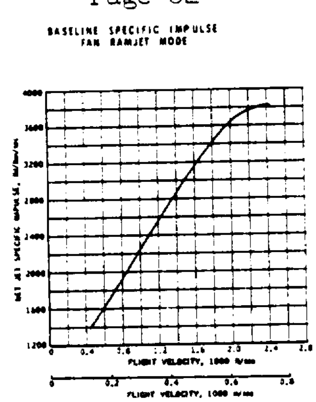
[redacted]

FAN PRESSURE RATIO EFFECT
FAN RAMJET MODE

Page 62

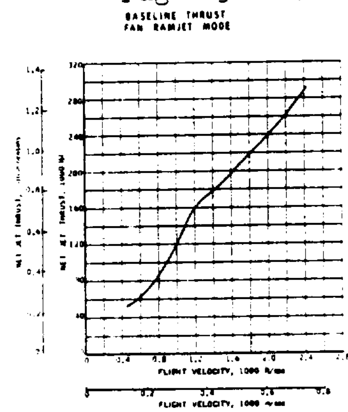


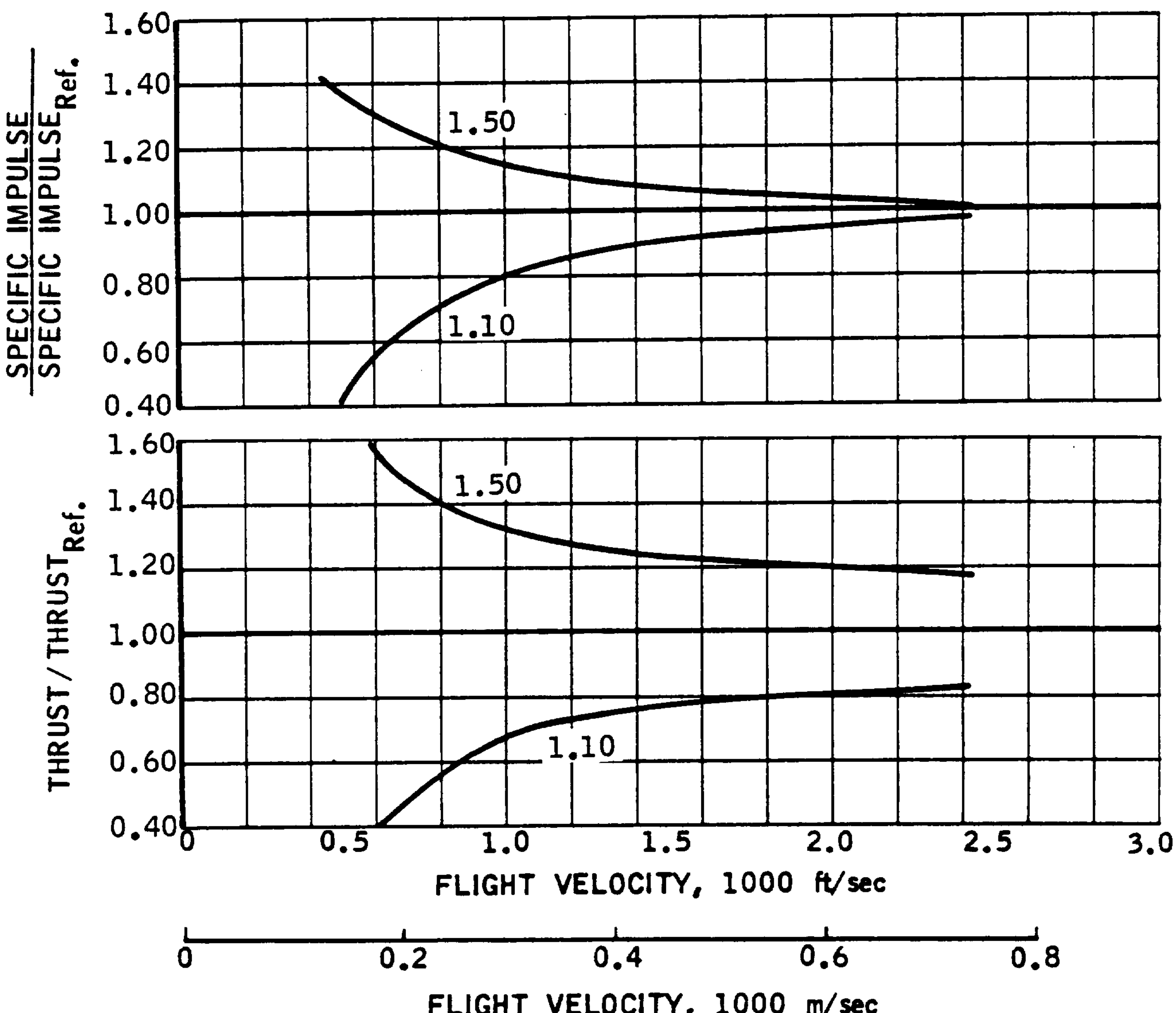
Eng. No. 11

Baseline

$PR_f = 1.30$

Page 63





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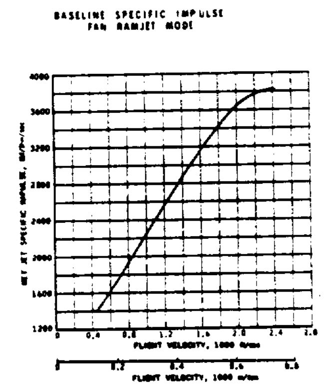
AFTERBURNER EQUIVALENCE RATIO EFFECT
FAN RAMJET MODE

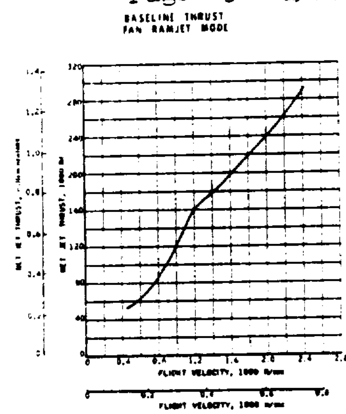
Page 62

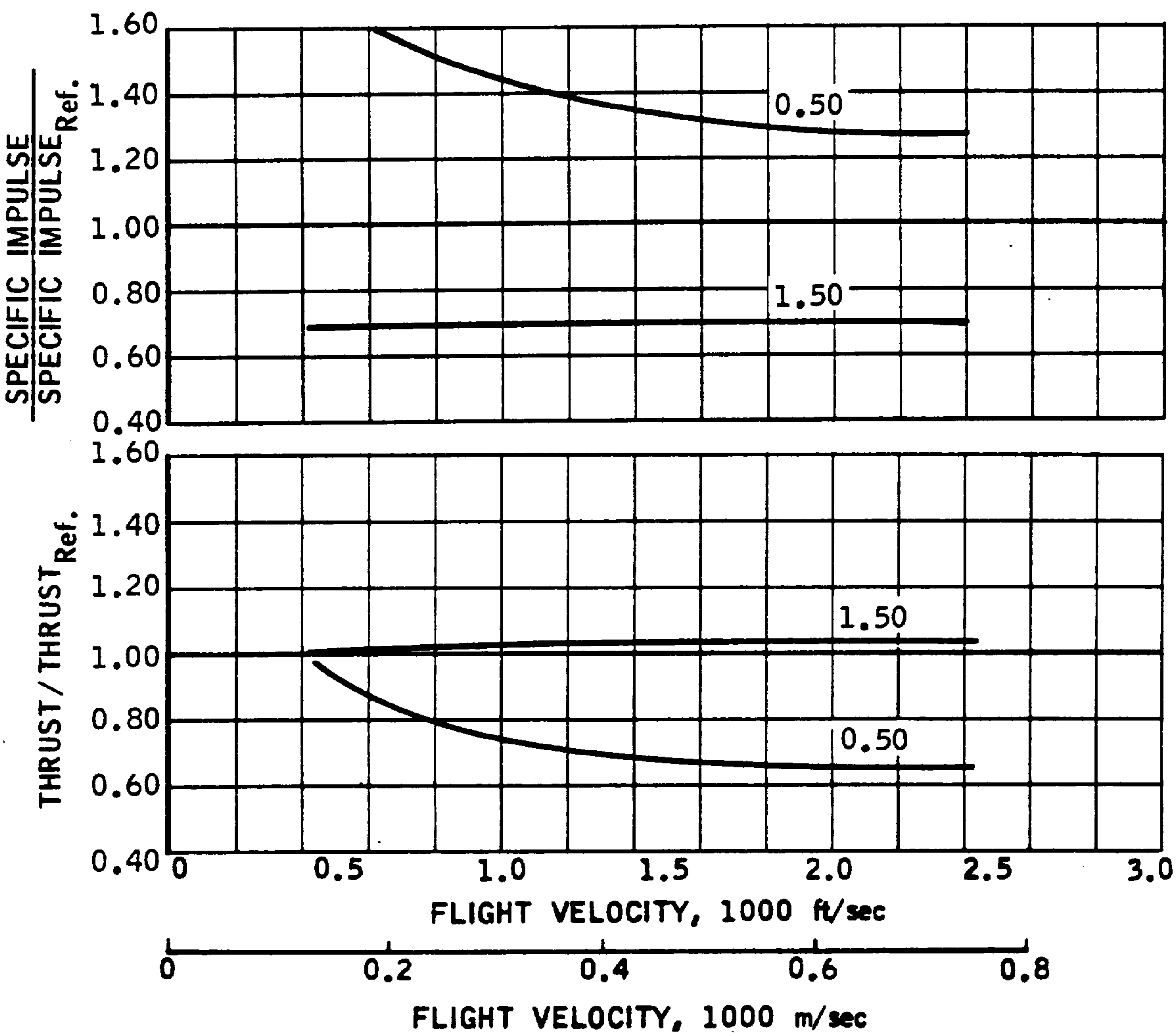


Eng. No. 11

Baseline
$\phi_{AB} = 1.00$

Page 63

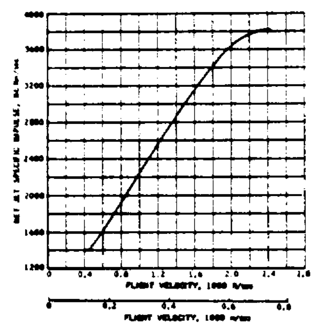




AFTERBURNER COMBUSTION EFFICIENCY EFFECT
FAN RAMJET MODE

Page 62 Eng. No. 11

BASELINE SPECIFIC IMPULSE FAN RAMJET MODE



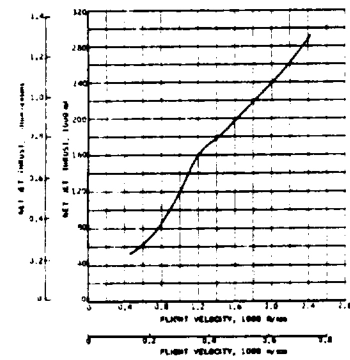
Eng. No. 11

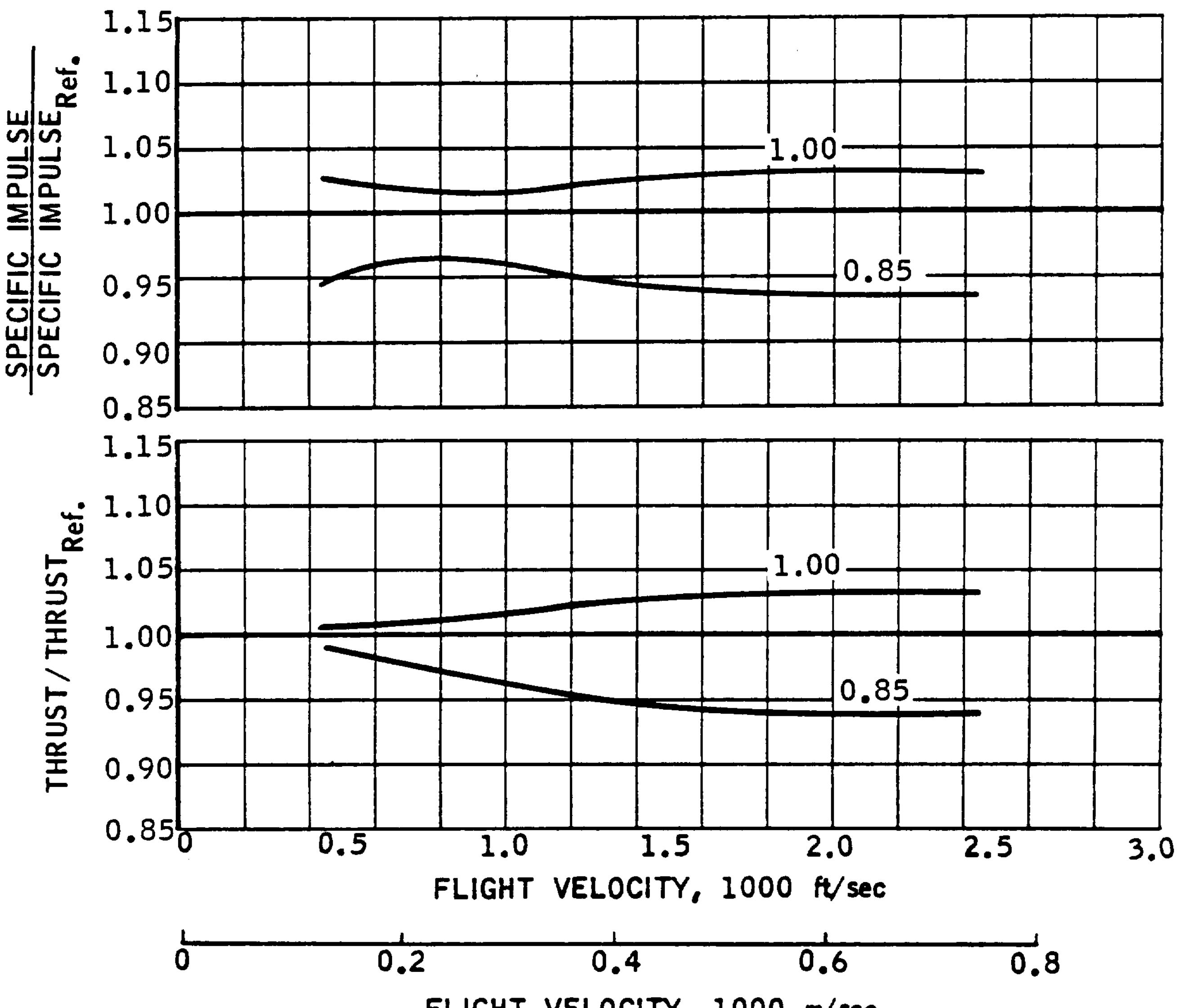
Baseline

$\eta_c = 0.95$

Page 63 Eng. No. 11

BASELINE THRUST FAN RAMJET MODE





[redacted]

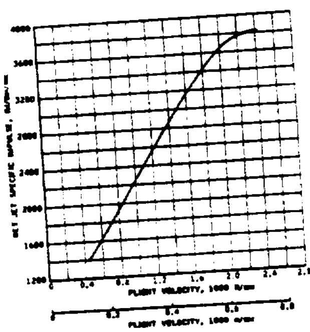
THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

EXIT NOZZLE EFFICIENCY EFFECT
FAN RAMJET MODE

Eng. No. 11

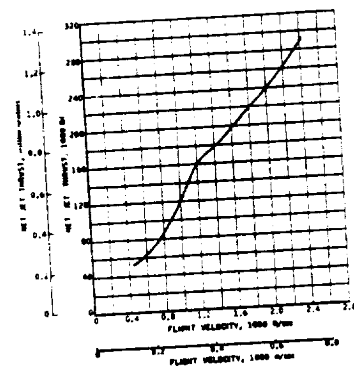
Page 62 Eng. No. 11

BASELINE SPECIFIC IMPULSE
FAN RAMJET MODE

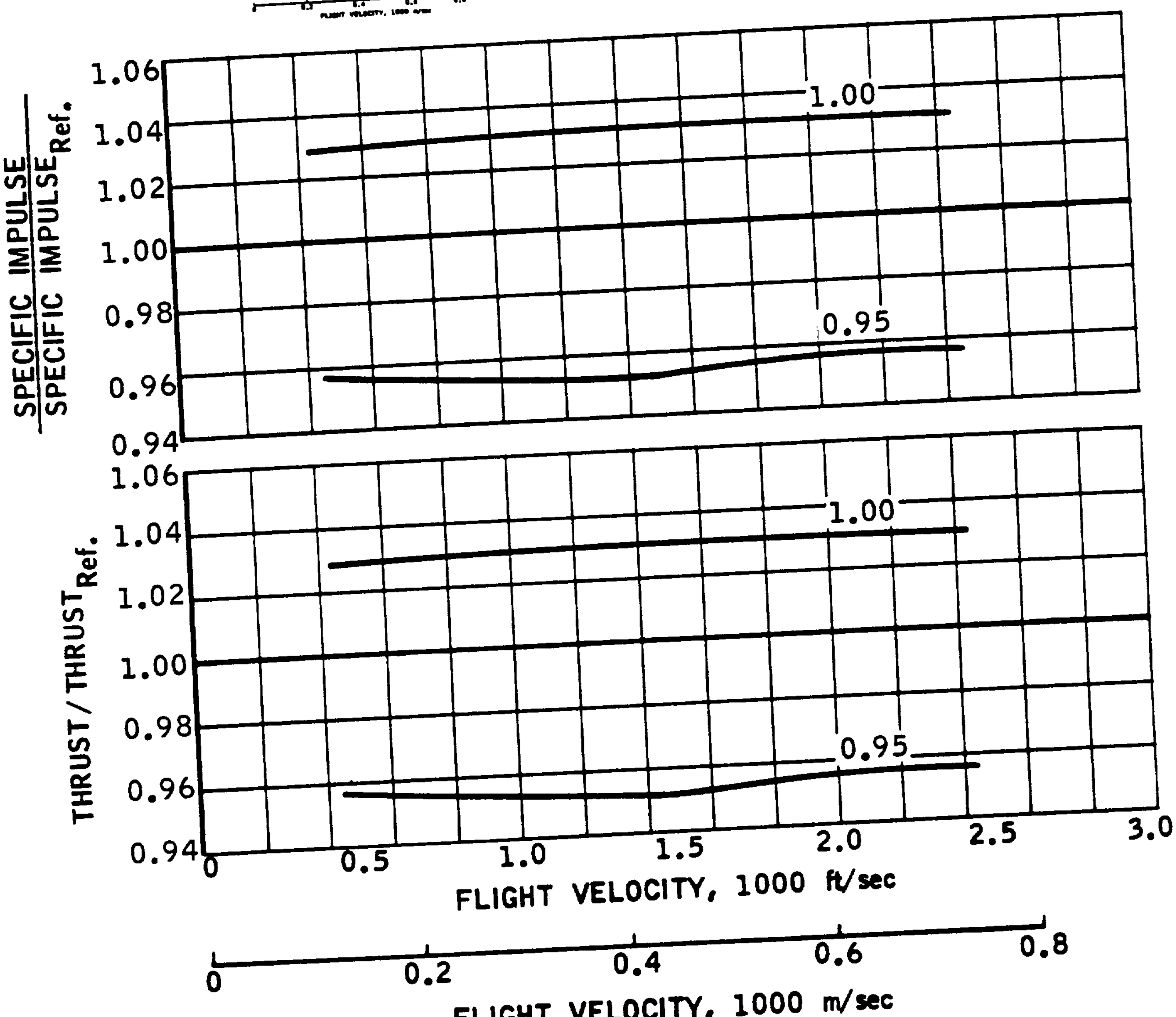


Page 63 Eng. No. 11

BASELINE THRUST
FAN RAMJET MODE



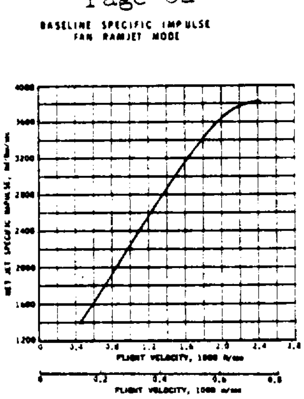
Baseline
$\eta_N = 0.98$



[redacted]

EXIT NOZZLE AREA RATIO EFFECT
FAN RAMJET MODE

Page 62



Eng. No. 11

Baseline
A_6/A_5:
Figure C
(Page 71)

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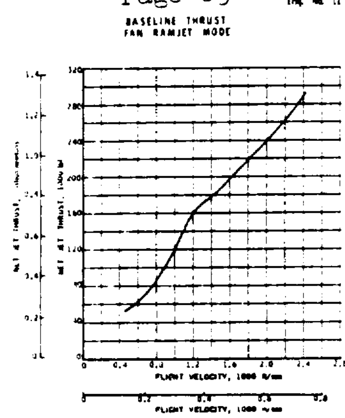
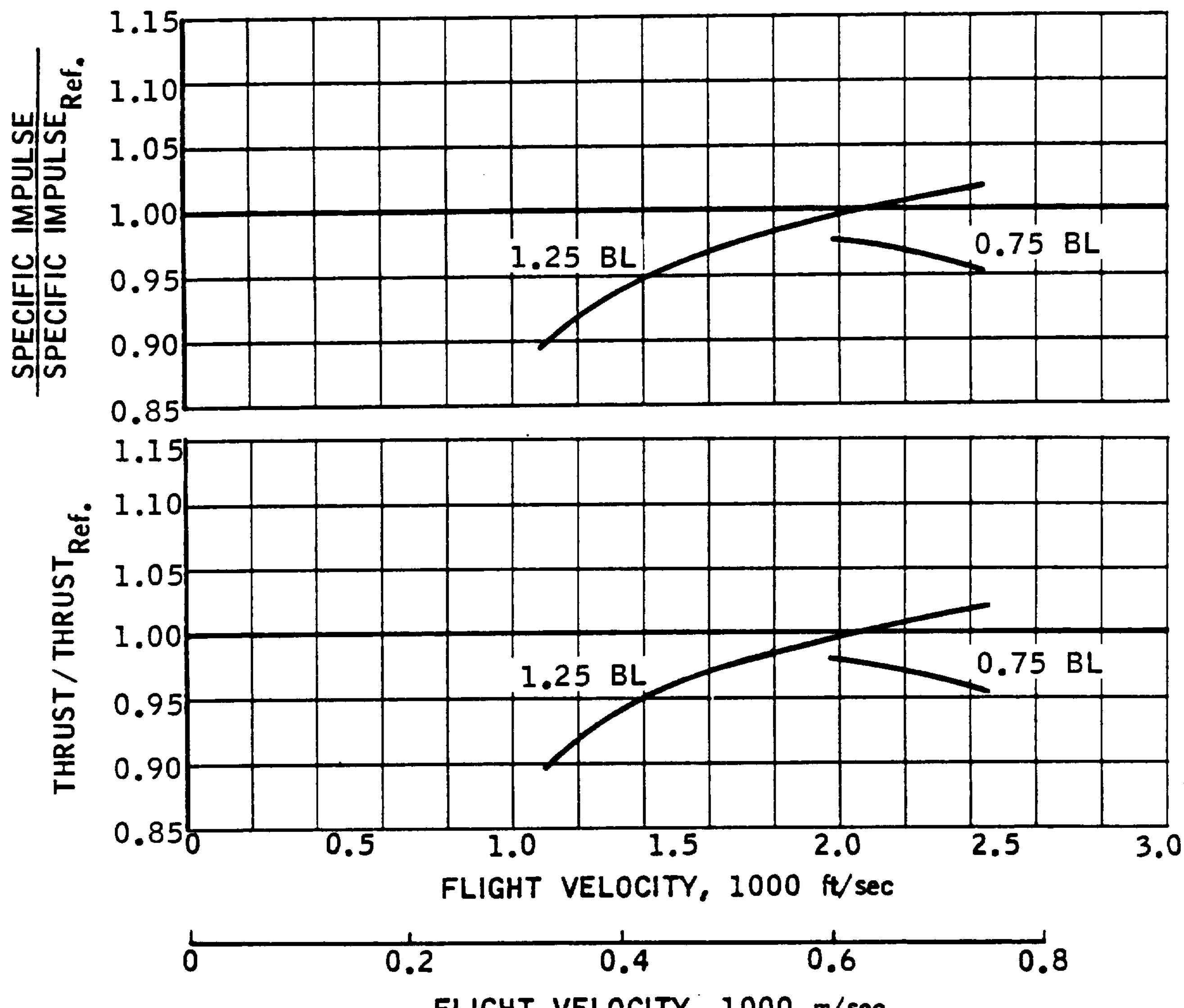


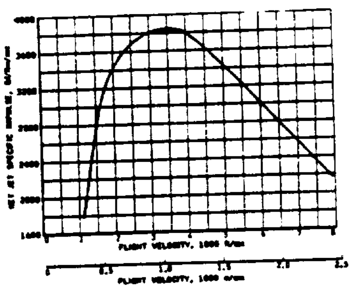


INLET PRESSURE RECOVERY EFFECT
RAMJET MODE

Eng. No. 11

Page 64

Eng. No. 11
BASELINE SPECIFIC IMPULSE
SUBSONIC COMBUSTION RAMJET



Baseline P_{T_2}/P_{T_0}: Figure A (Page 69)

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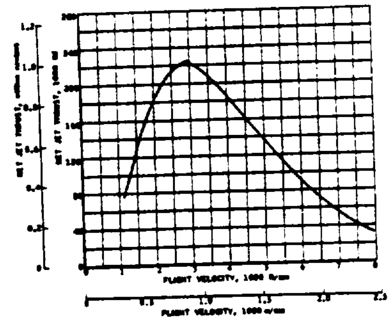
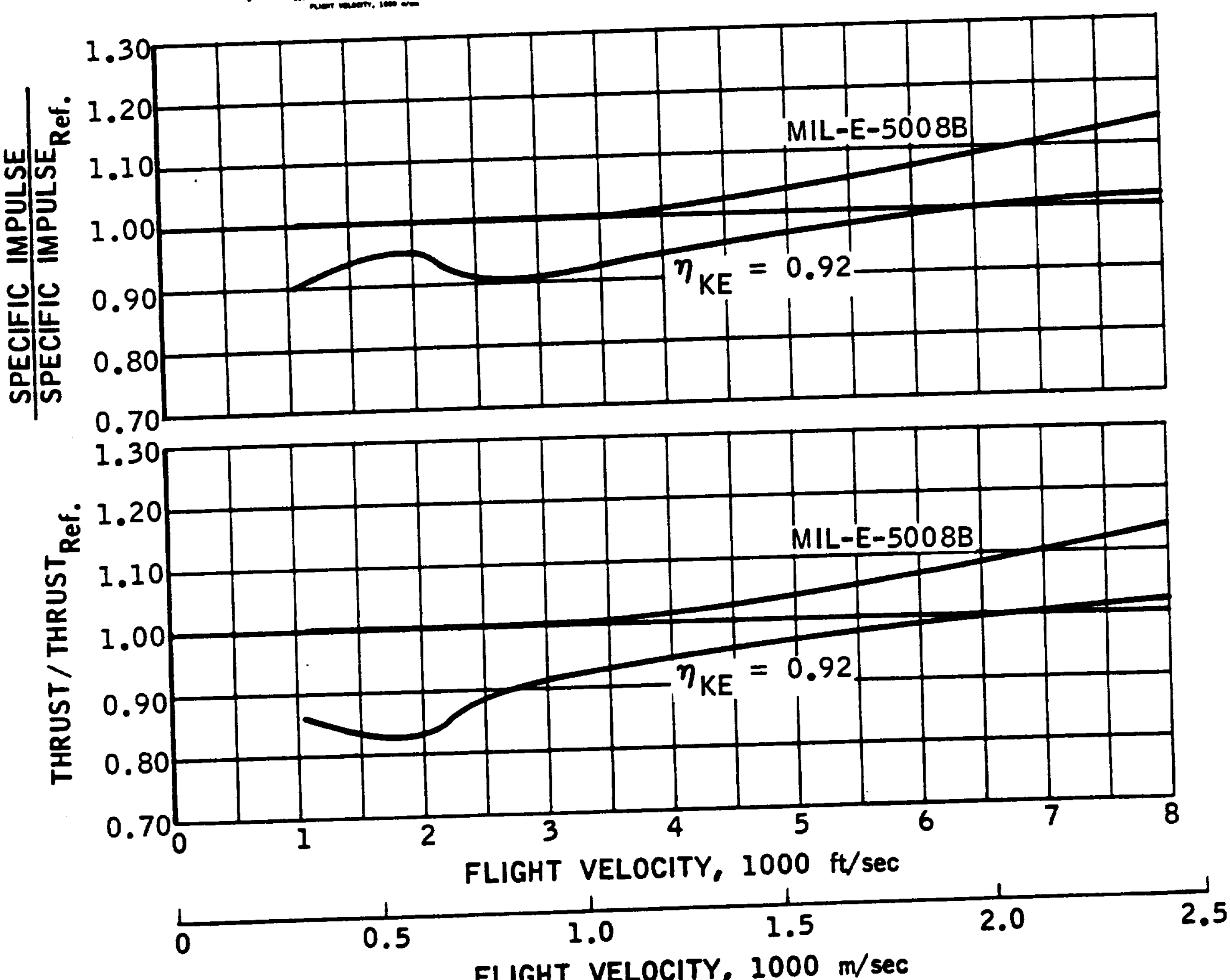
Eng. No. 11
BASELINE THRUST
SUBSONIC COMBUSTION RAMJET





AFTERBURNER EQUIVALENCE RATIO EFFECT
RAMJET MODE

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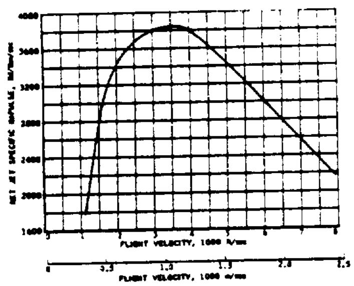
Eng. No. 11

BASELINE SPECIFIC IMPULSE
SUBSONIC COMBUSTION RAMJET



Eng. No. 11

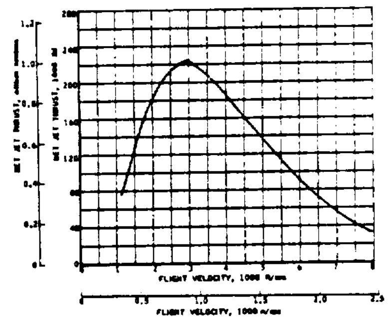
Baseline

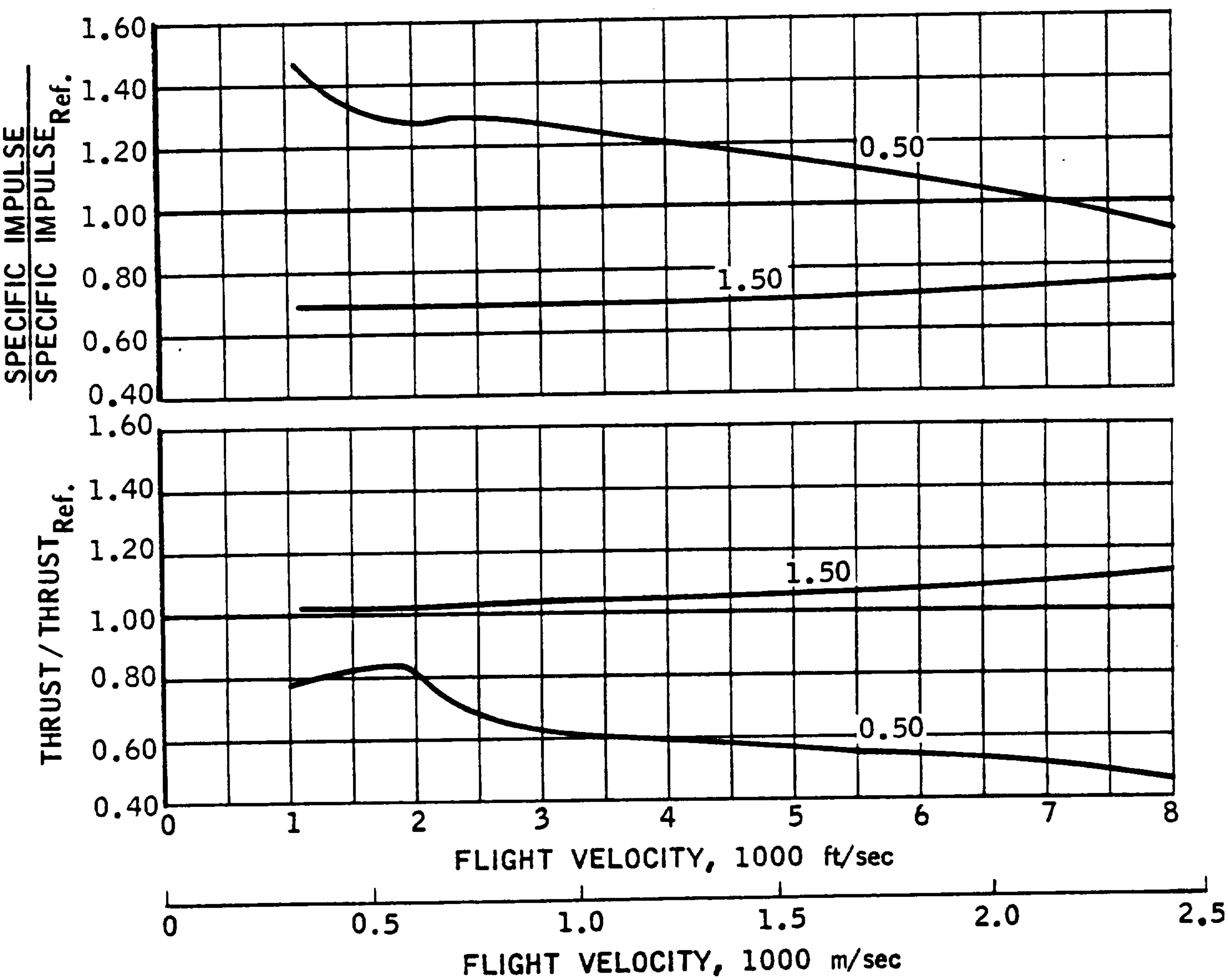
$\phi = 1.00$

Page 65

Eng. No. 11

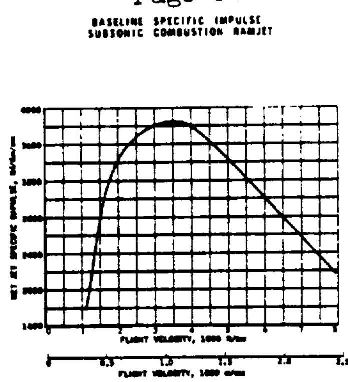
BASELINE THRUST
SUBSONIC COMBUSTION RAMJET





AFTERBURNER COMBUSTION EFFICIENCY EFFECT
RAMJET MODE

Page 64

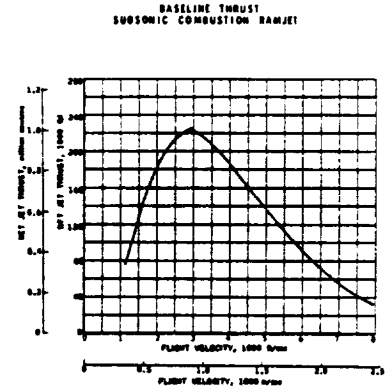


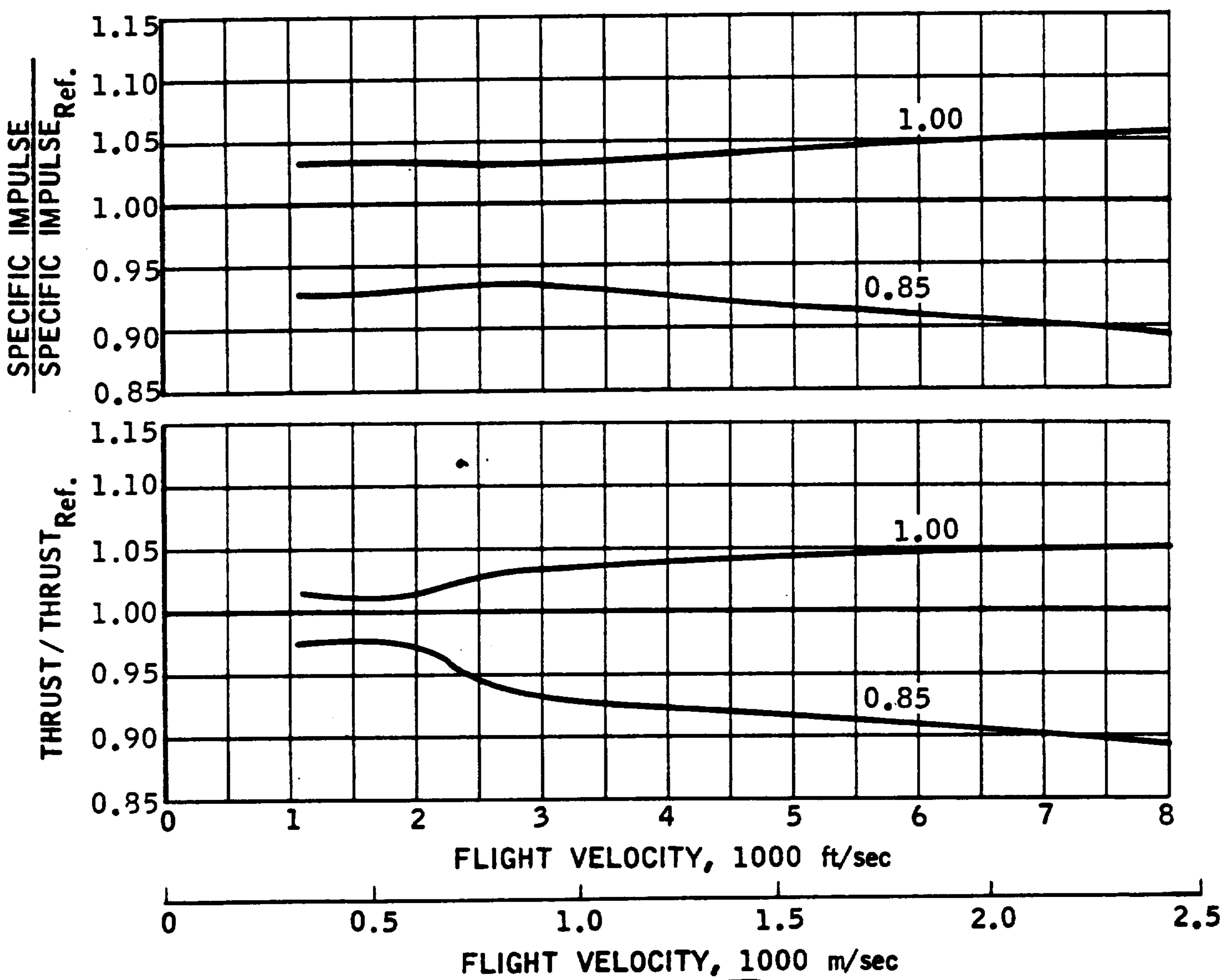
Eng. No. 11

Baseline

$\eta_c = 0.95$

Page 65





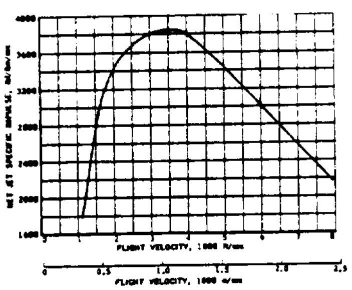
[redacted]

EXIT NOZZLE EFFICIENCY EFFECT
RAMJET MODE

Page 64

Eng. No. 11

BASELINE SPECIFIC IMPULSE
SUBSONIC COMBUSTION RAMJET



Eng. No. 11

Baseline

$\eta_N = 0.98$

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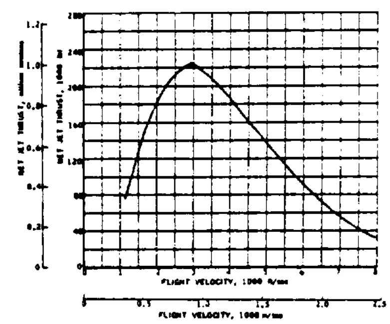
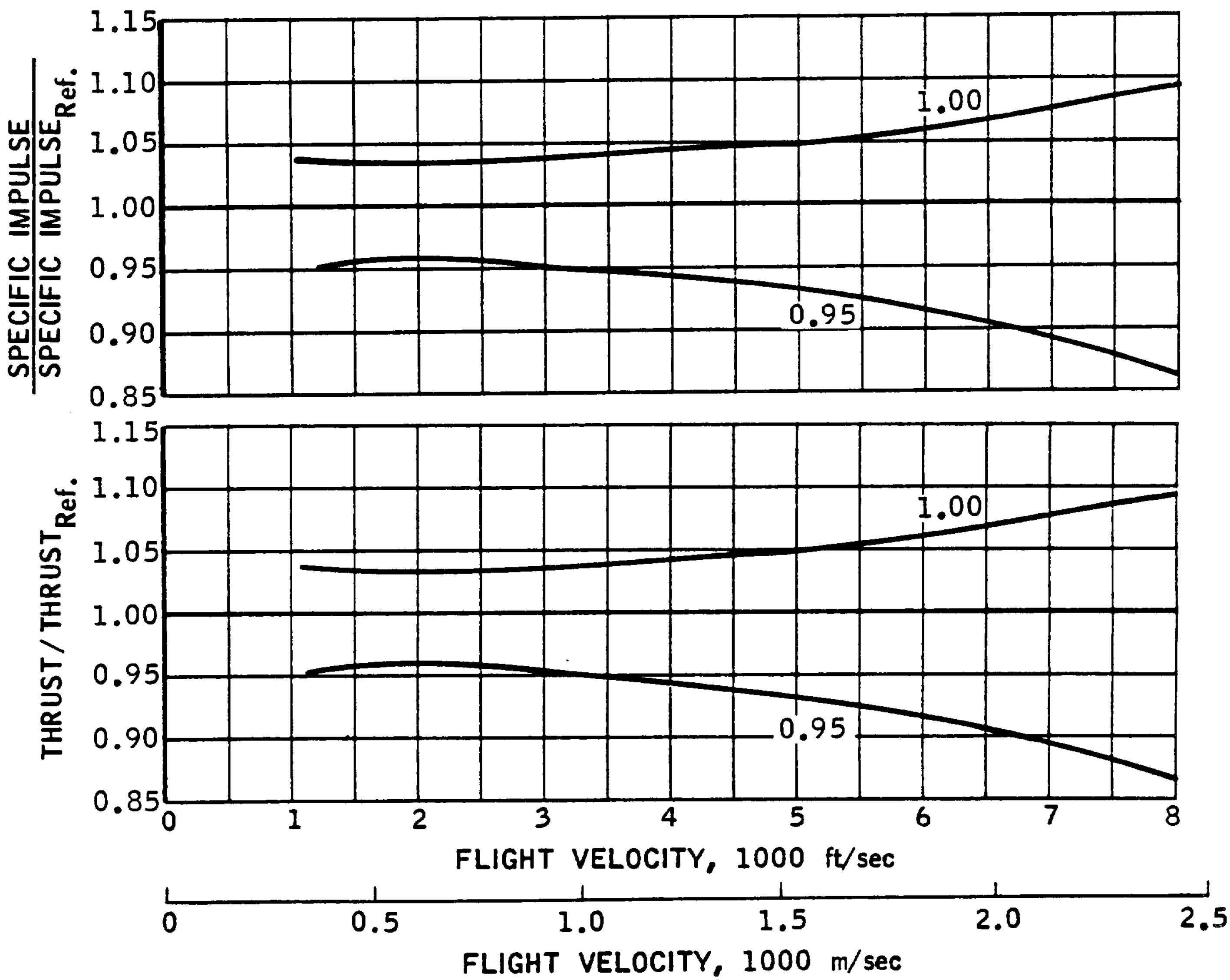
Eng. No. 11

BASELINE THRUST
SUBSONIC COMBUSTION RAMJET





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EXIT NOZZLE AREA RATIO EFFECT

RAMJET MODE

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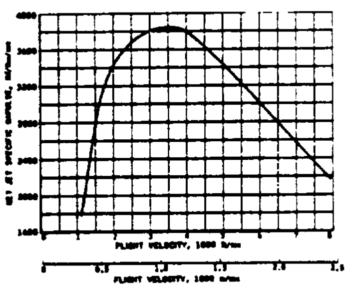
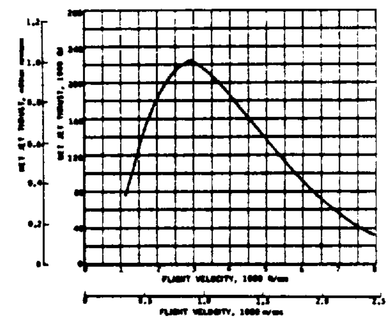


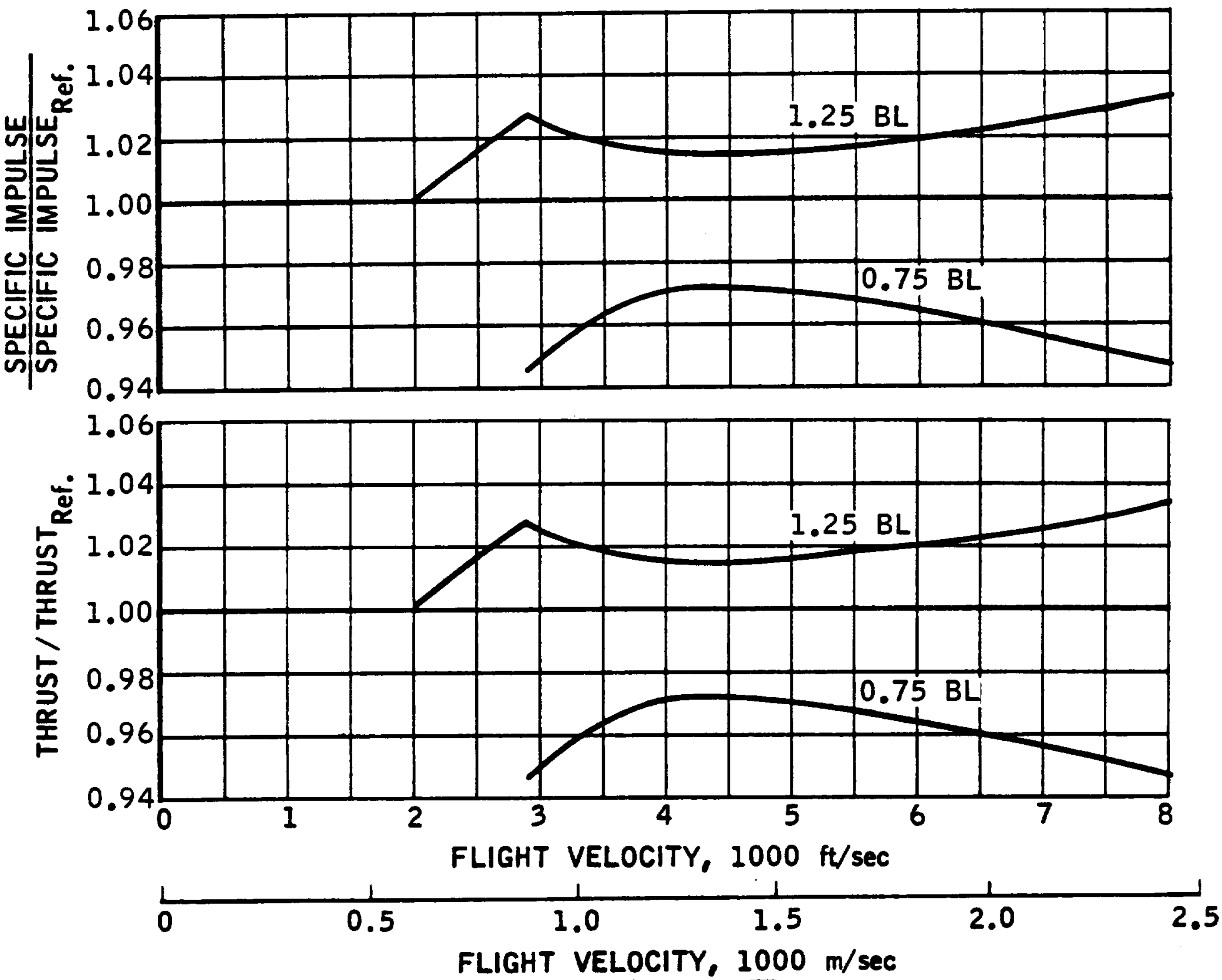
Eng. No. 11

Baseline

A_6/A_5:
Figure D
(Page 72)

Page 65





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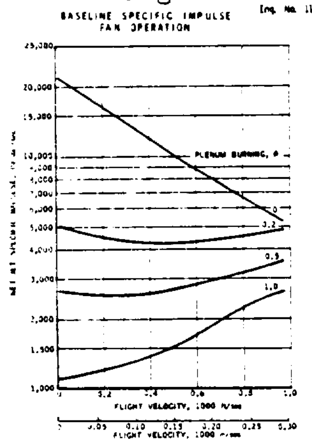
INLET PRESSURE RECOVERY EFFECT

FAN OPERATION

Page 66

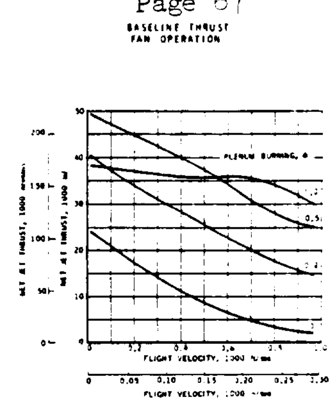


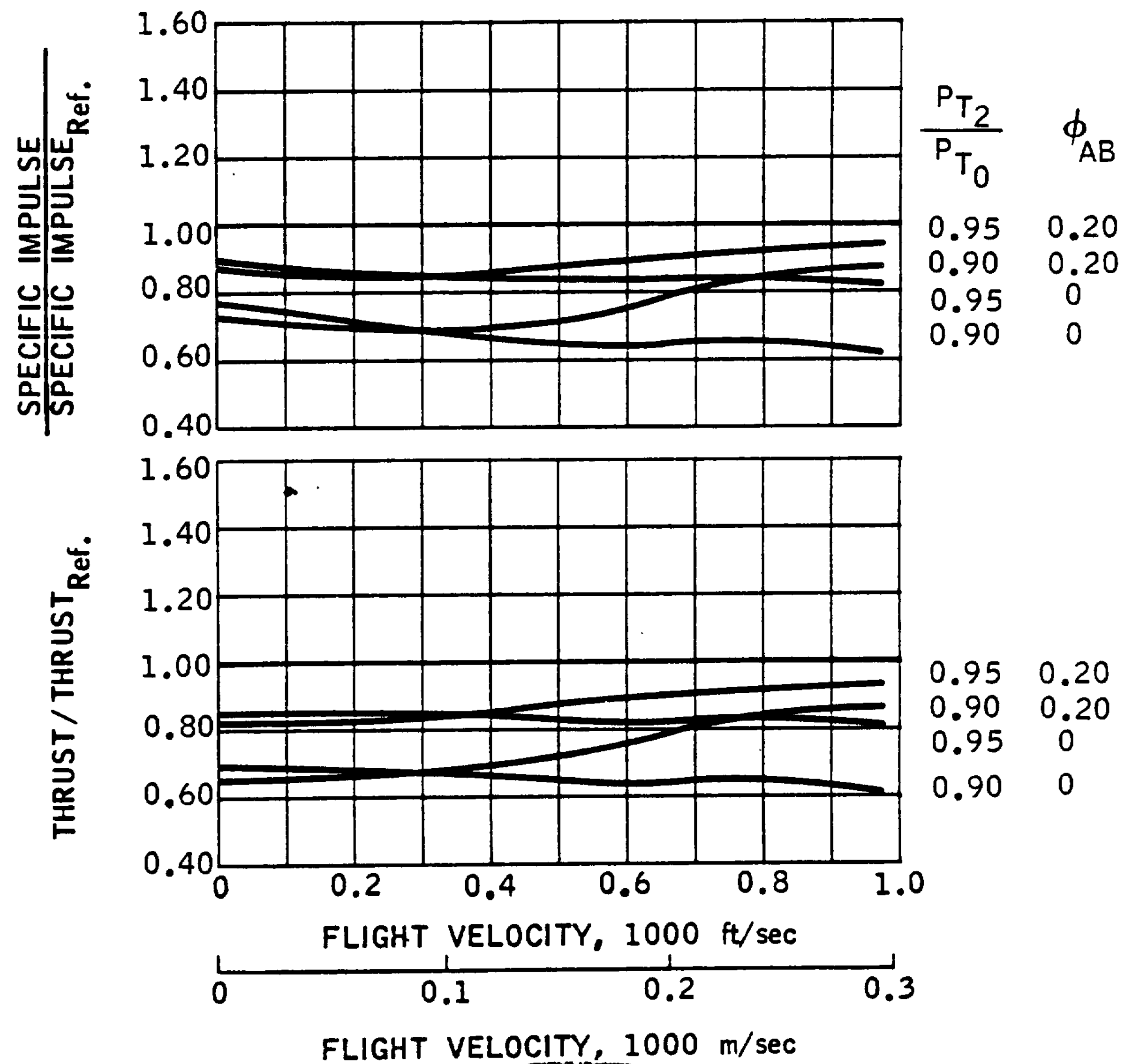
Eng. No. 11

Baseline

$P_{T_2} / P_{T_0} = 1.00$

Page 67





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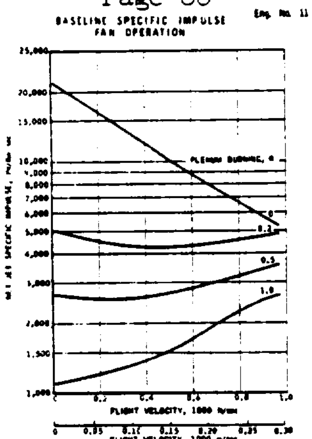
INLET PRESSURE RECOVERY EFFECT
FAN OPERATION

Page 66

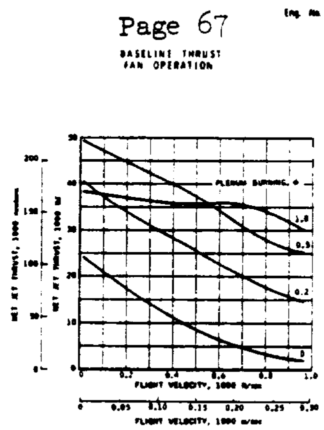


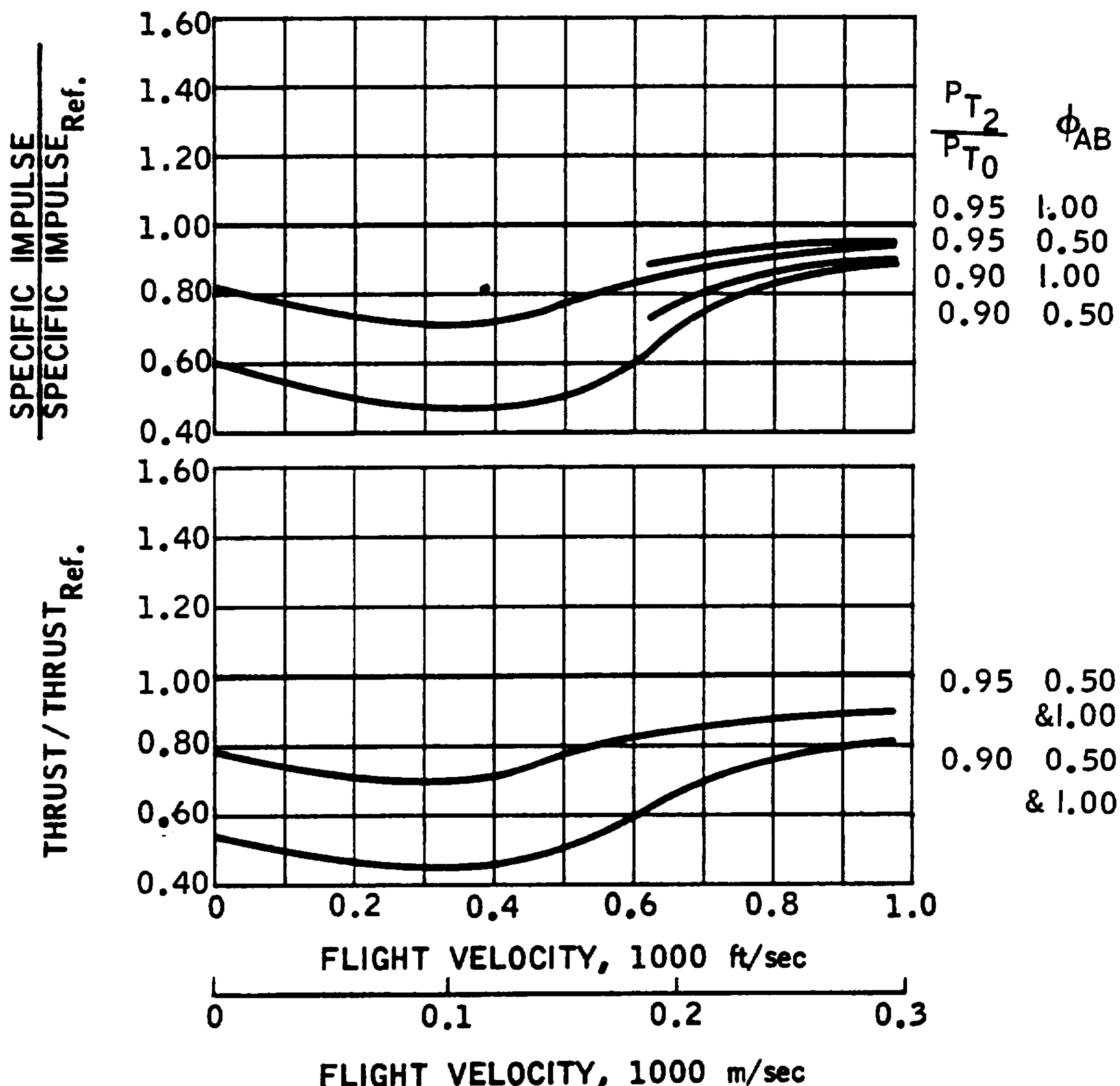
Eng. No. 11

Baseline

$P_{T_2}/P_{T_0} = 1.00$

Page 67





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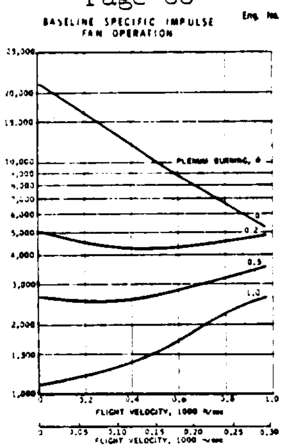
FAN PRESSURE RATIO EFFECT

FAN OPERATION

Page 66

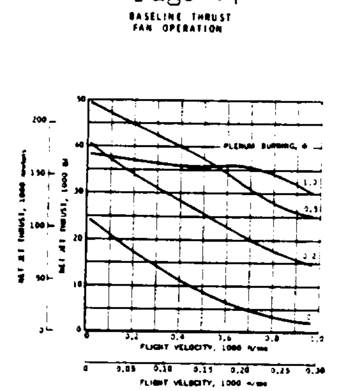


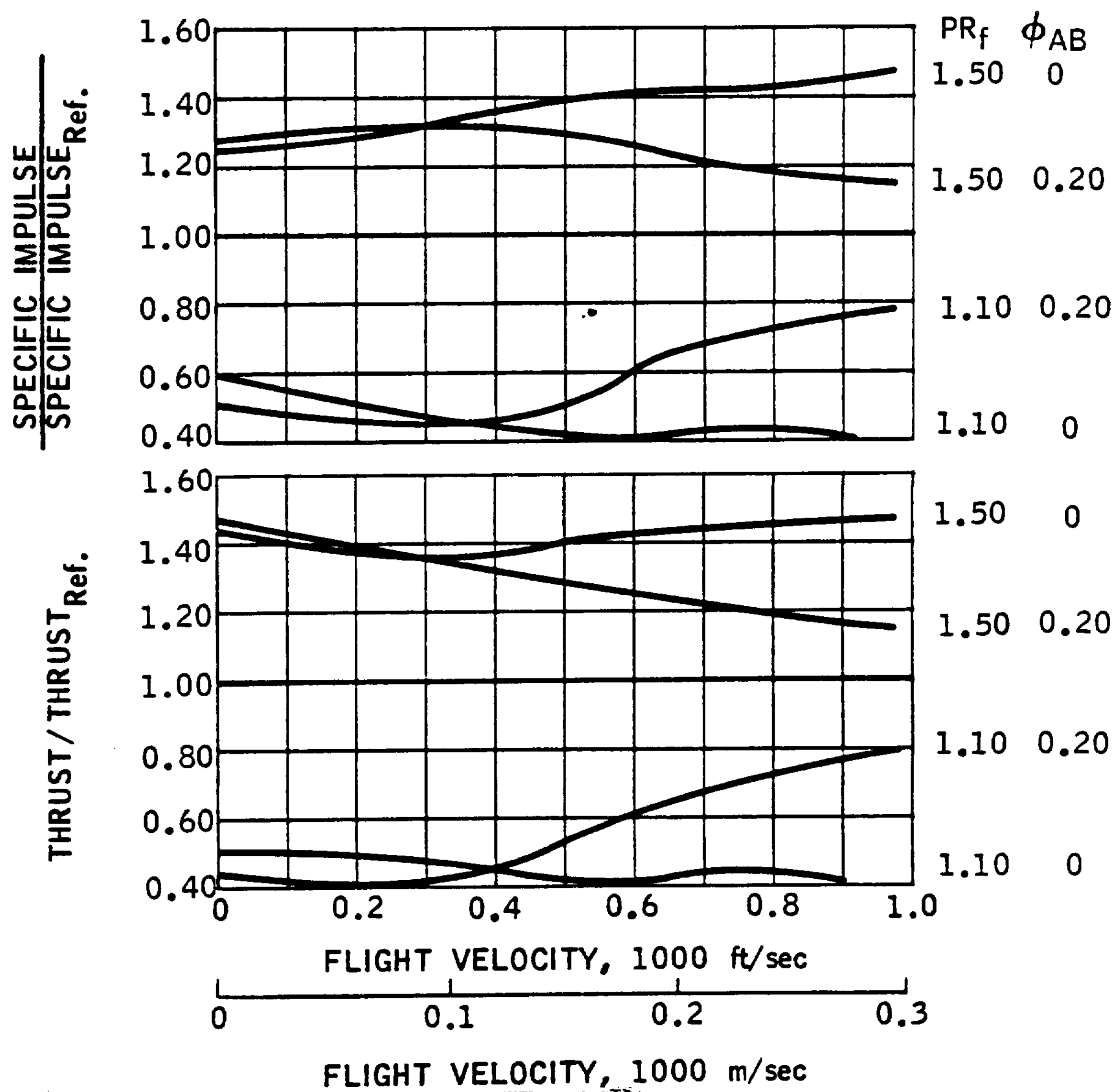
Eng. No. 11

Baseline

$PR_f = 1.30$

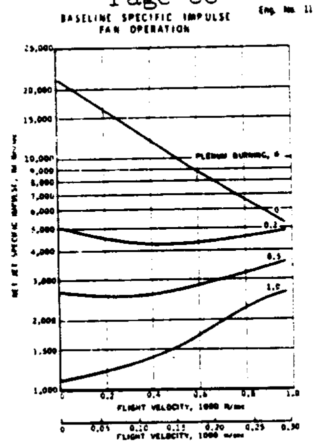
Page 67





FAN PRESSURE RATIO EFFECT
FAN OPERATION

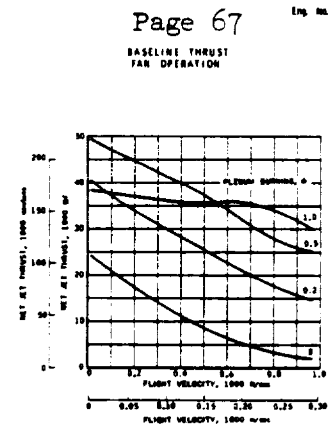
Page 66

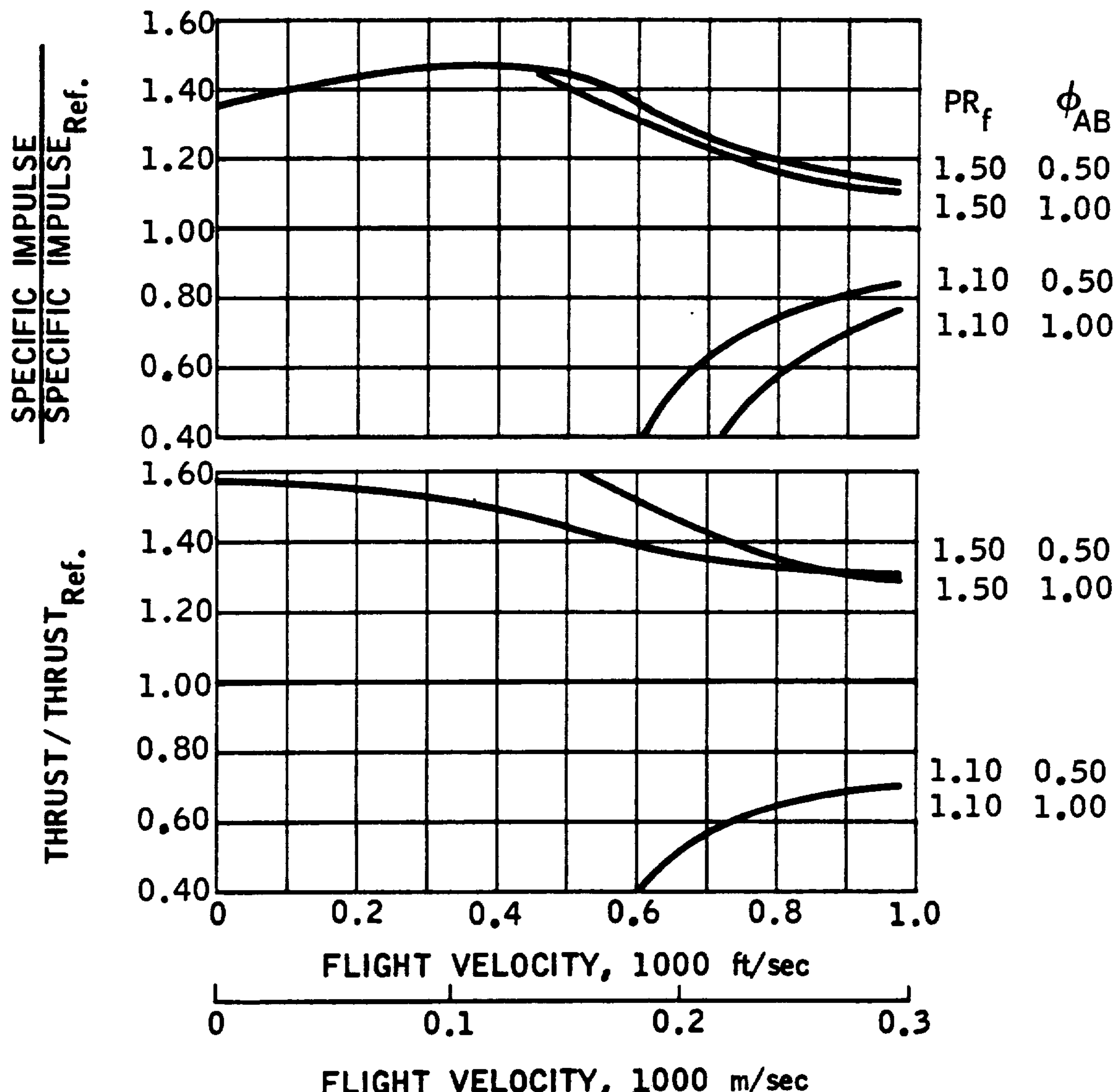


Eng. No. 11

Baseline
$PR_f = 1.30$

Page 67





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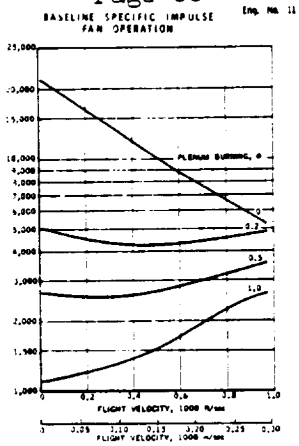
AFTERBURNER COMBUSTION EFFICIENCY EFFECT

FAN OPERATION

Page 66

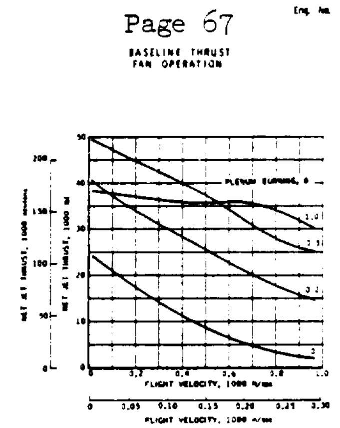


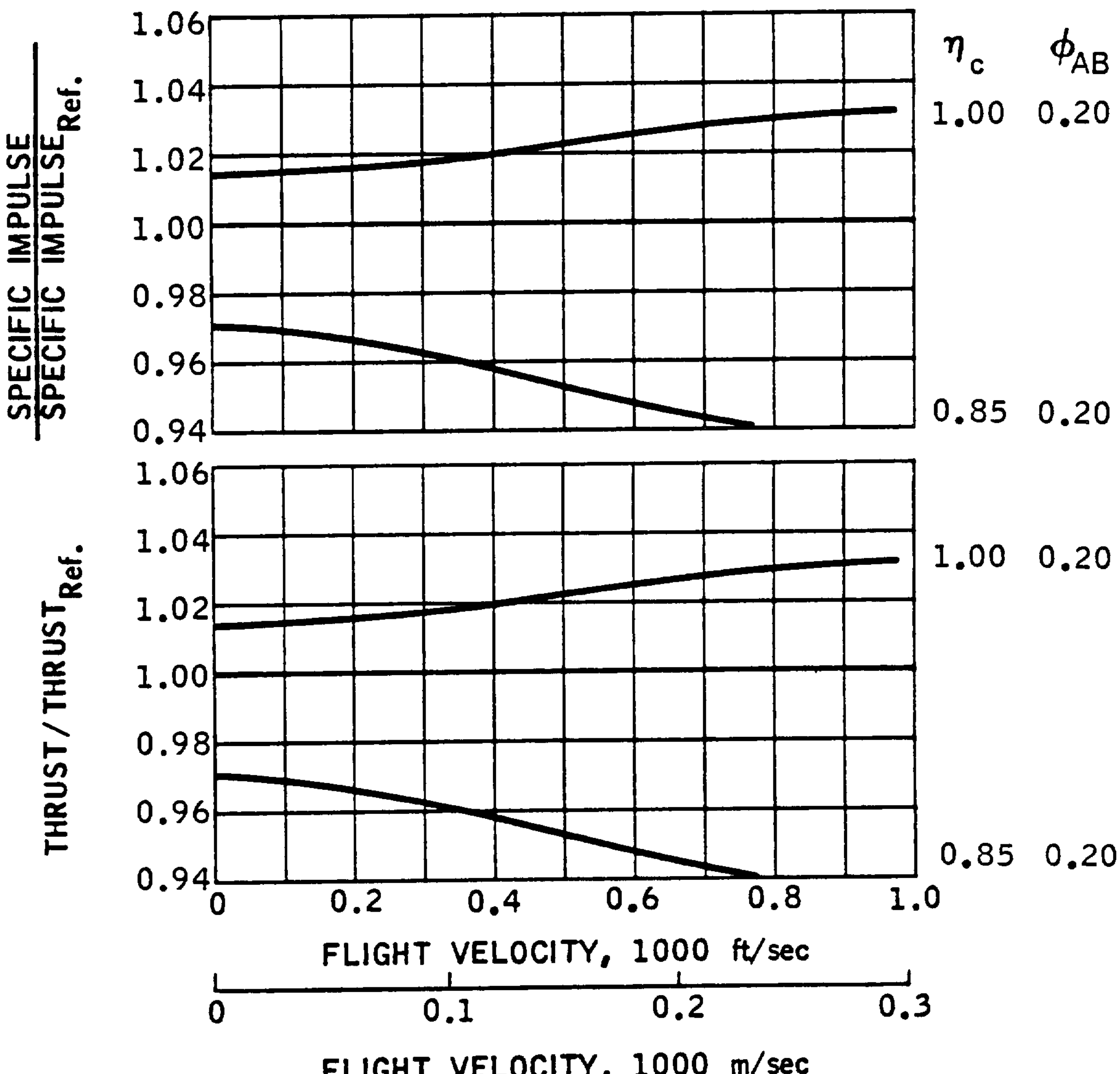
Eng. No. 11

Baseline

$\eta_c = 0.95$

Page 67





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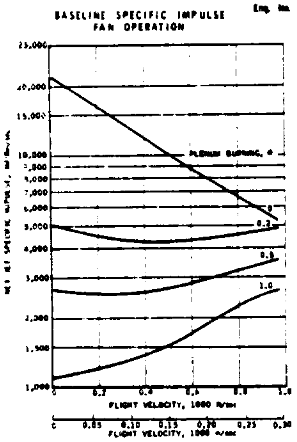
AFTERBURNER COMBUSTION EFFICIENCY EFFECT

FAN OPERATION

Page 66

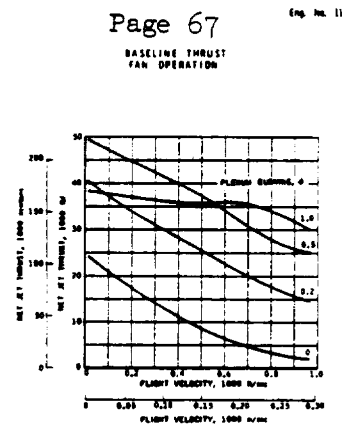


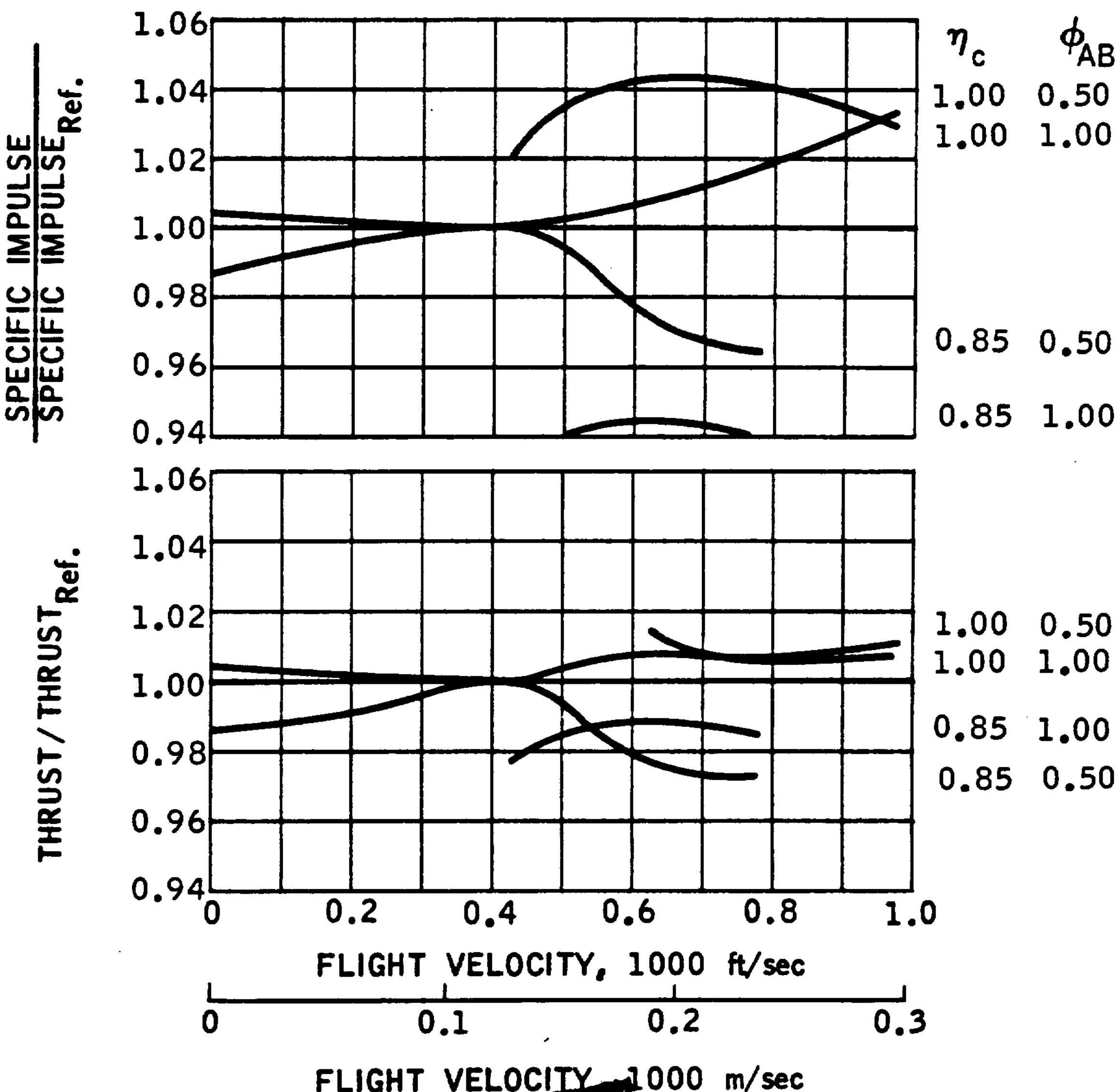
Eng. No. 11

Baseline

$\eta_c = 0.95$

Page 67





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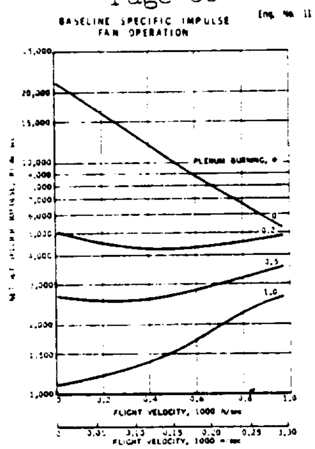
EXIT NOZZLE EFFICIENCY EFFECT
FAN OPERATION

Page 66

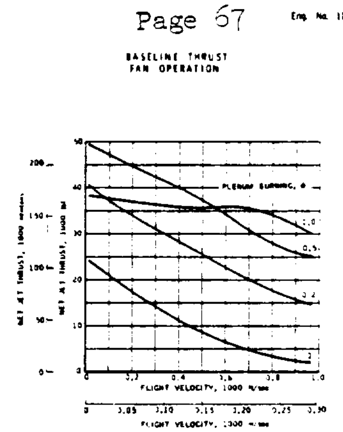


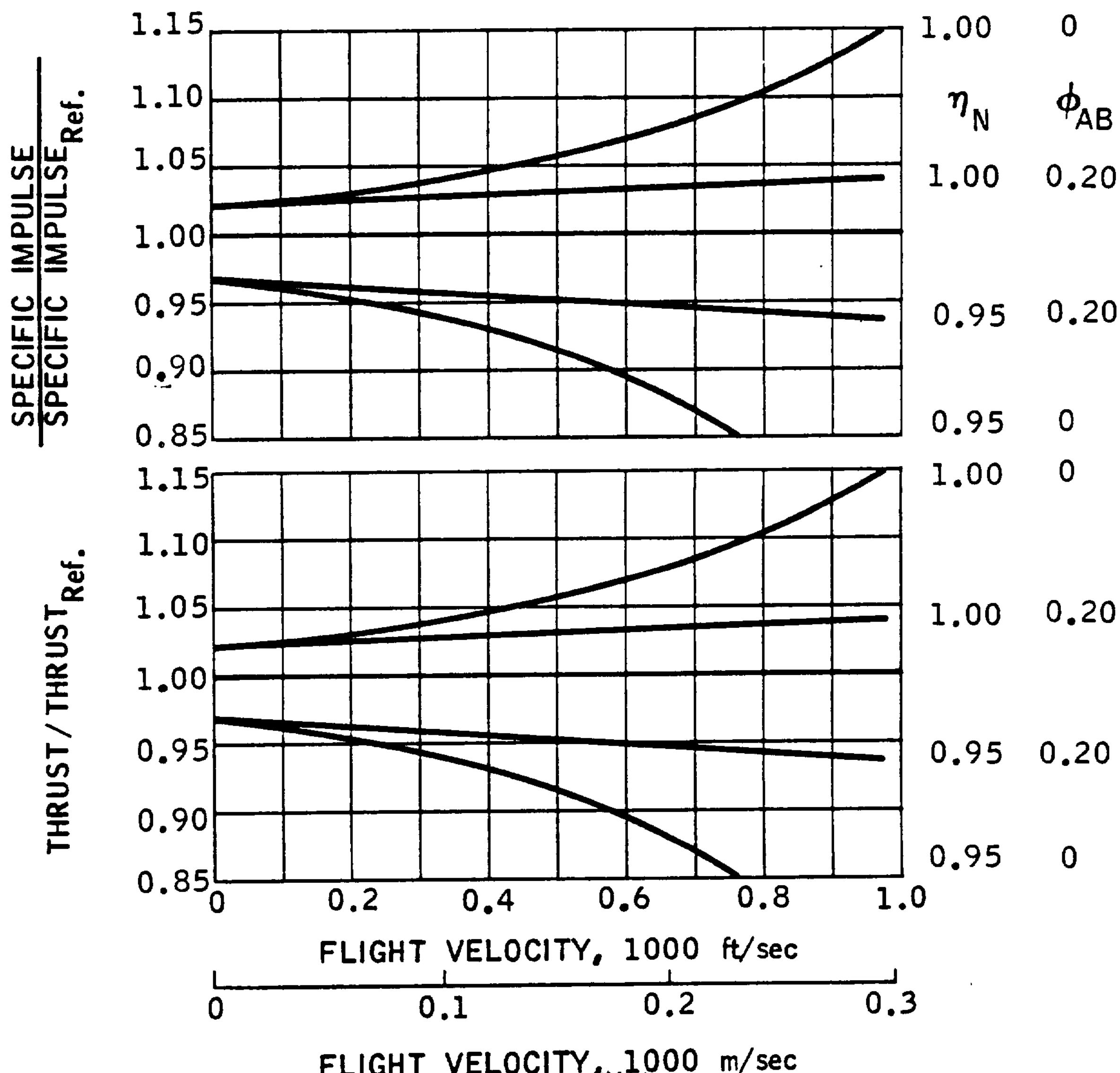
Eng. No. 11

Baseline

$\eta_N = 0.98$

Page 67





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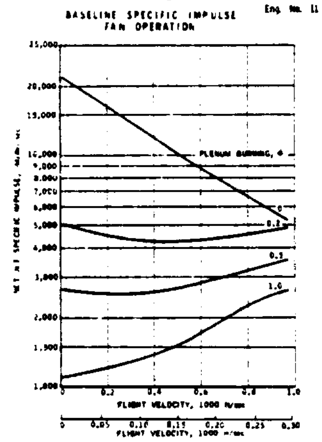
EXIT NOZZLE EFFICIENCY EFFECT
FAN OPERATION

Page 66

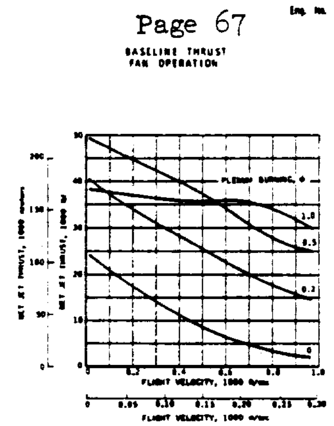


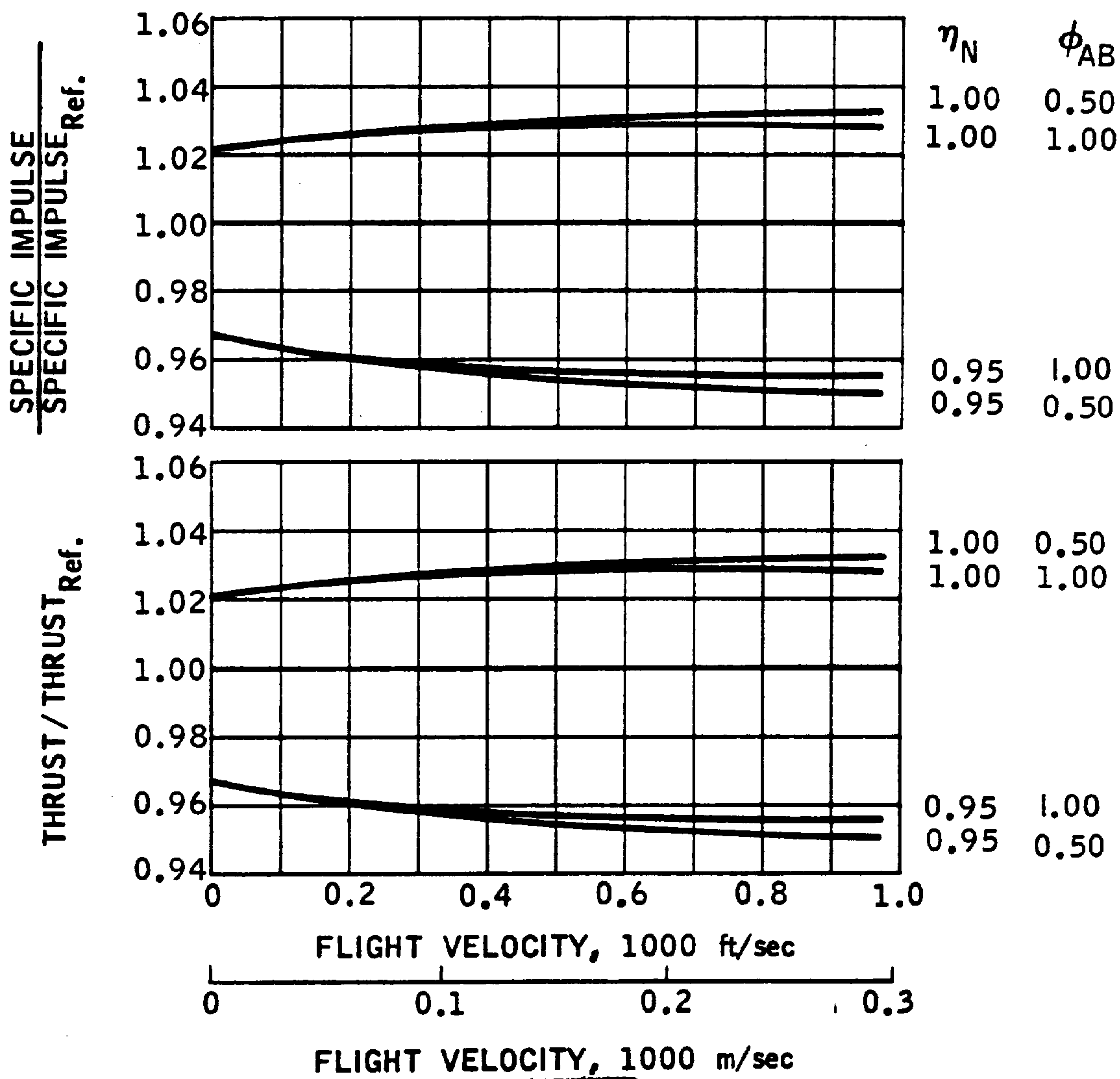
Eng. No. 11

Baseline

$\eta_N = 0.98$

Page 67





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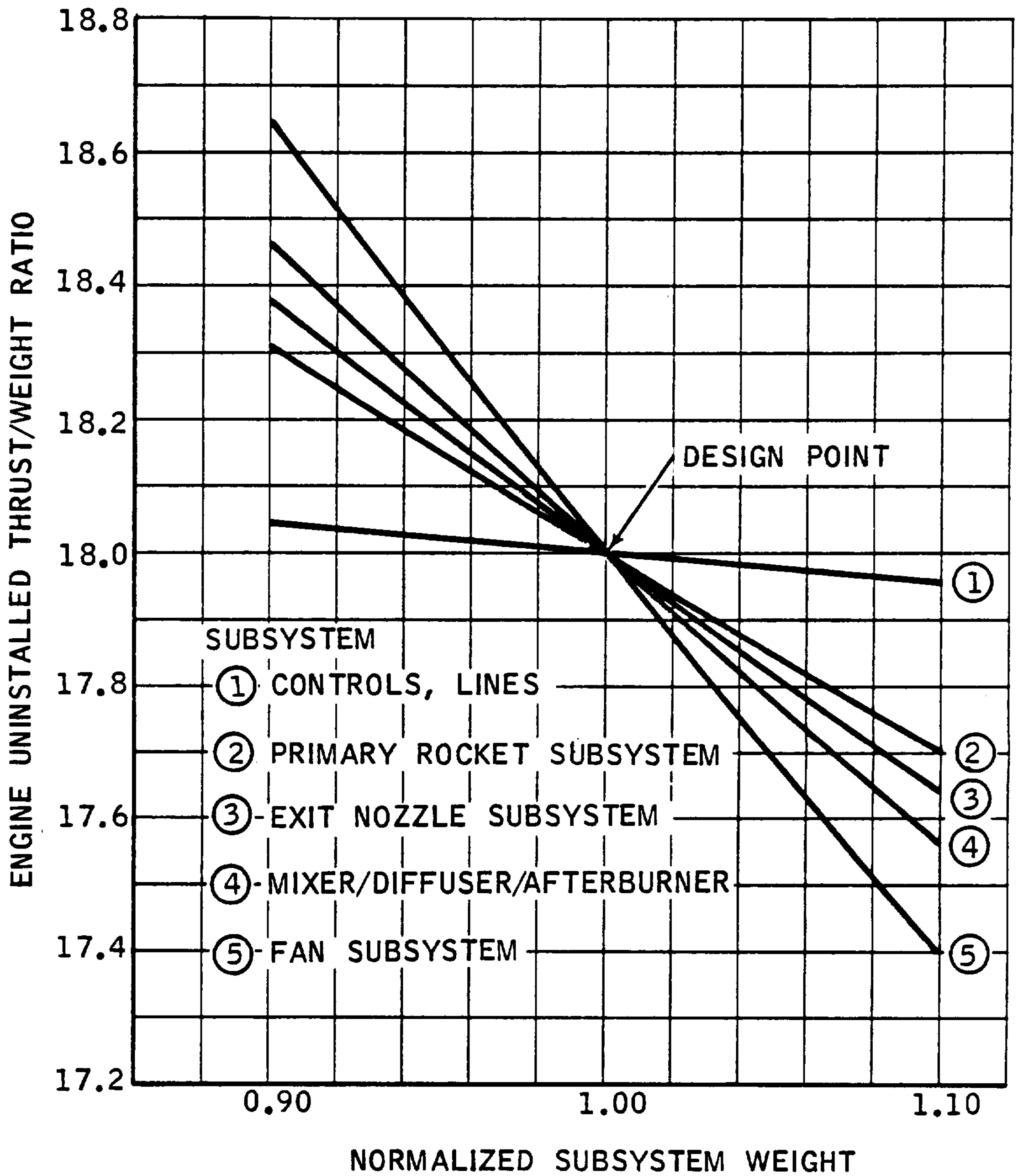
Eng. No. 11

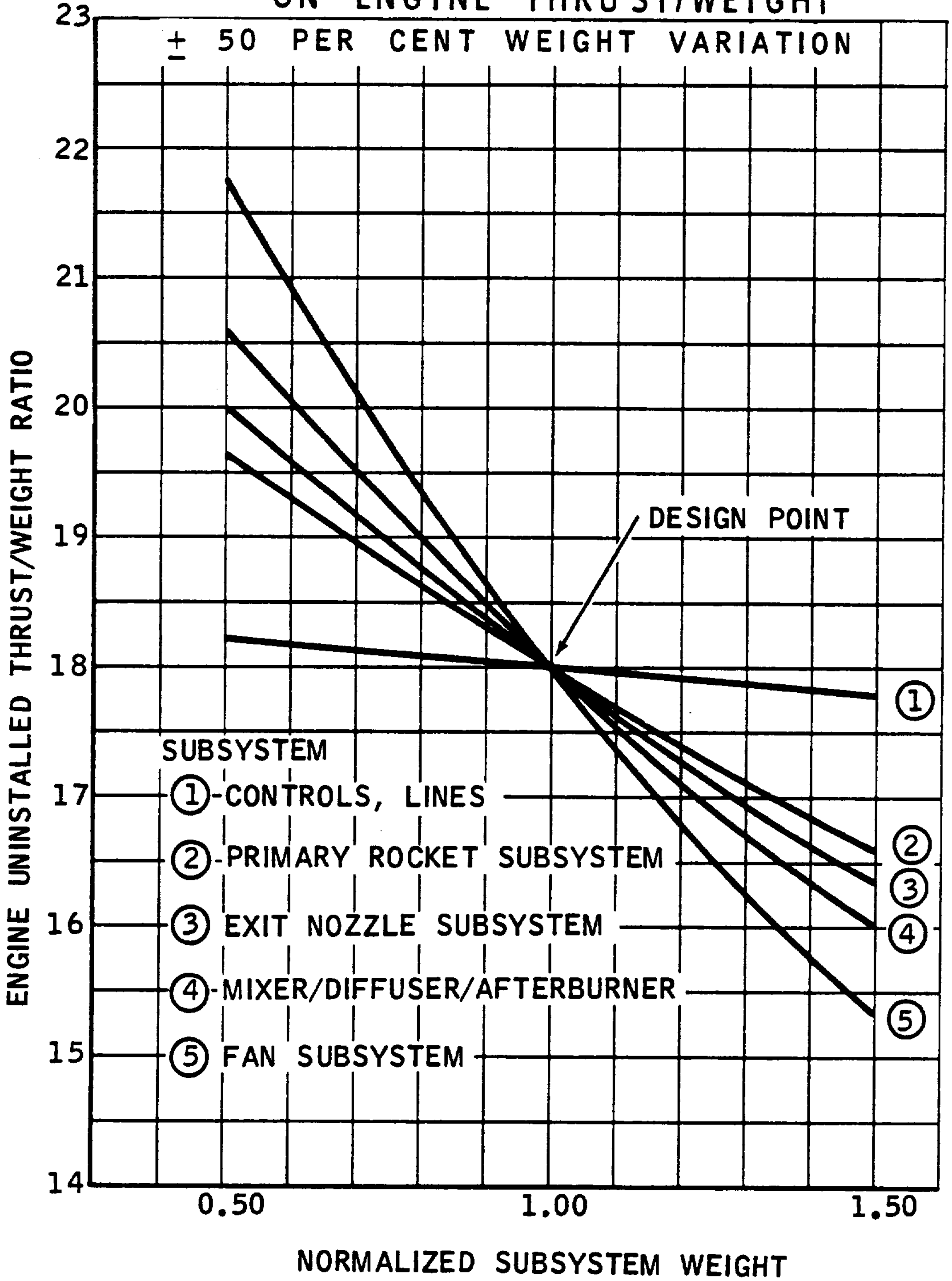
EFFECT OF SUBSYSTEM WEIGHT VARIATION ON ENGINE THRUST/WEIGHT

± 10 PER CENT WEIGHT VARIATION

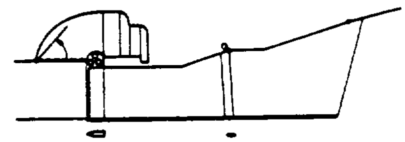


Eng. No. 11

EFFECT OF SUBSYSTEM WEIGHT VARIATION ON ENGINE THRUST/WEIGHT



SCRAMLACE, NO. 22



The ScramLACE powerplant (Engine No. 22, Class 2 Study Phase) is a 173,000 lbf thrust (sea level static) engine with Mach 12 flight speed capability. The fuel is liquid hydrogen, with an auxiliary supply of liquid oxygen required for gas generator drive purposes. The engine normally operates in three progressive modes: (1) liquid air cycle ejector mode, (2) subsonic combustion ramjet mode and (3) supersonic combustion ramjet mode. Primarily because of SCRAMJET considerations, the engine has been packaged in a two dimensional configuration. The uninstalled engine weighs 10,457 lbm, providing a sea level static thrust/weight ratio of 16.5.

The basic design specifiers are: Design mass flow ratio 1.5 to 1, primary chamber pressure 1000 psia, maximum internal pressure 100 psia, and an air liquefaction heat exchanger equivalence ratio of 8 to 1. The overall length of the uninstalled engine is 300 in. (7.65 meters), the width is 142 in. (3.6 meters). The overall height is 102.5 in. (2.6 meters).

The engine comprises a light-weight air liquefaction heat exchanger assembly consisting of a precooler and condenser unit ducted together in a low pressure shell constructed of reinforced plastic. All pumps are driven by bi-propellant gas generators. The heat exchanger assembly is capable of being closed during the high speed modes.

The primary rocket assembly consists of eleven (11) regeneratively cooled vertical two-dimensional linear bell rocket strips. These units act, also, as mechanical supports for the supersonic combustion ramjet fuel injectors. Aft of the rectangular mixing section and diffuser is another series of cooled vertical struts which inject the afterburner and subsonic burning ramjet mode fuel.

Exit throat area control is effected by four vertically hinged cooled exit panels which close from the engine walls and a center structure. This throat variability is consistent with ramjet (subsonic combustion) and ejector mode performance cited herein. For supersonic combustion the panels are faired in line providing minimum drag losses.

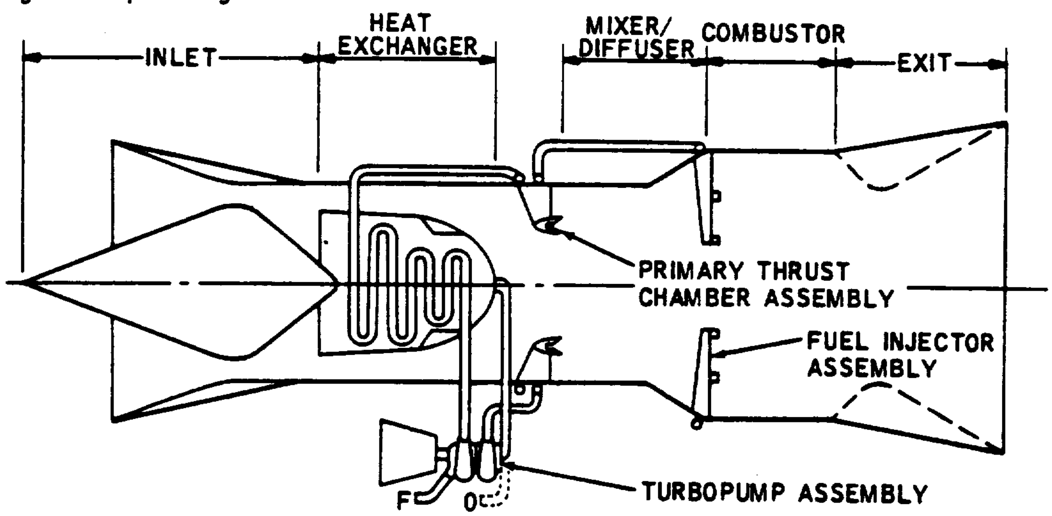
All internal engine surfaces are regeneratively cooled during all modes of engine operation. The basic panel structure of the engine consists of light weight composite structure consisting of a thin-gage, multiple wall internal surface cooled by double passed hydrogen, supported through a bonded compliant layer of elastromeric compound by an externally insulated berrylium honeycomb structure.

The engine was sized for a 1 million lbm gross weight horizontal takeoff two-stage launch vehicle. The engine was utilized in a complement of six (6) units mounted along the bottom side of a high fineness ratio, low drag lifting body design. The inlet comprised a two-dimensional moving ramp, variable geometry, mixed external and internal compression unit. Exit gases are considered to be further expanded during the high speed flight modes against the underside of the vehicle in order to maximize supersonic combustion ramjet performance.

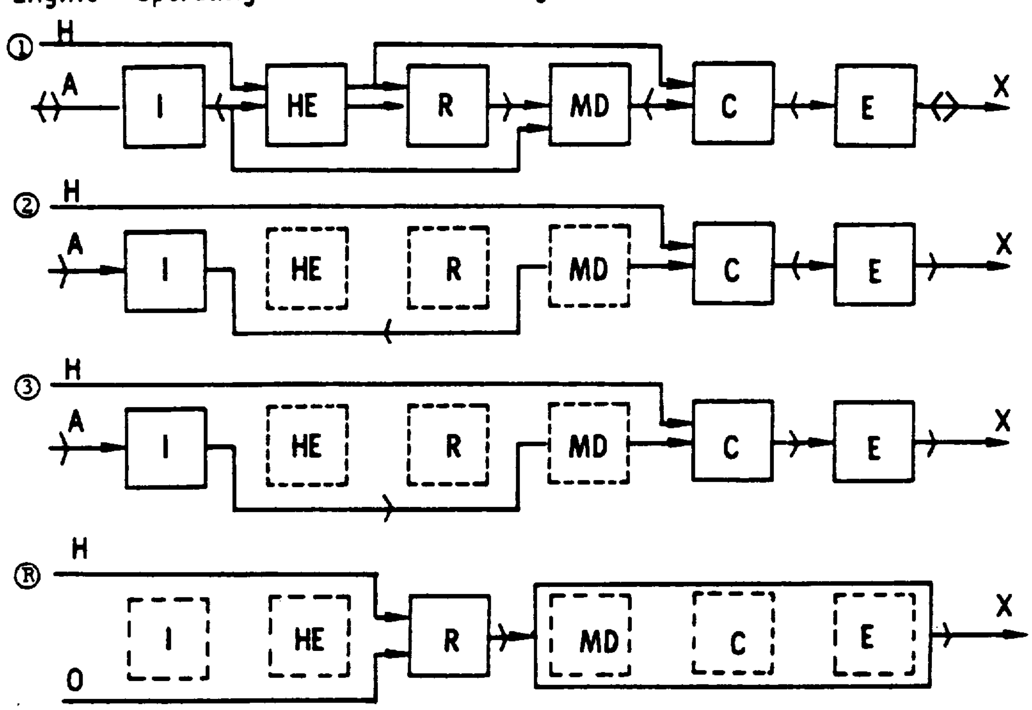
[redacted]

Eng. No. 22

Engine Operating Schematic



Engine Operating Mode Block Diagrams *



*Note: Mode numerical coding is given on Page 105,
"R" denotes optional all-rocket mode.

CON

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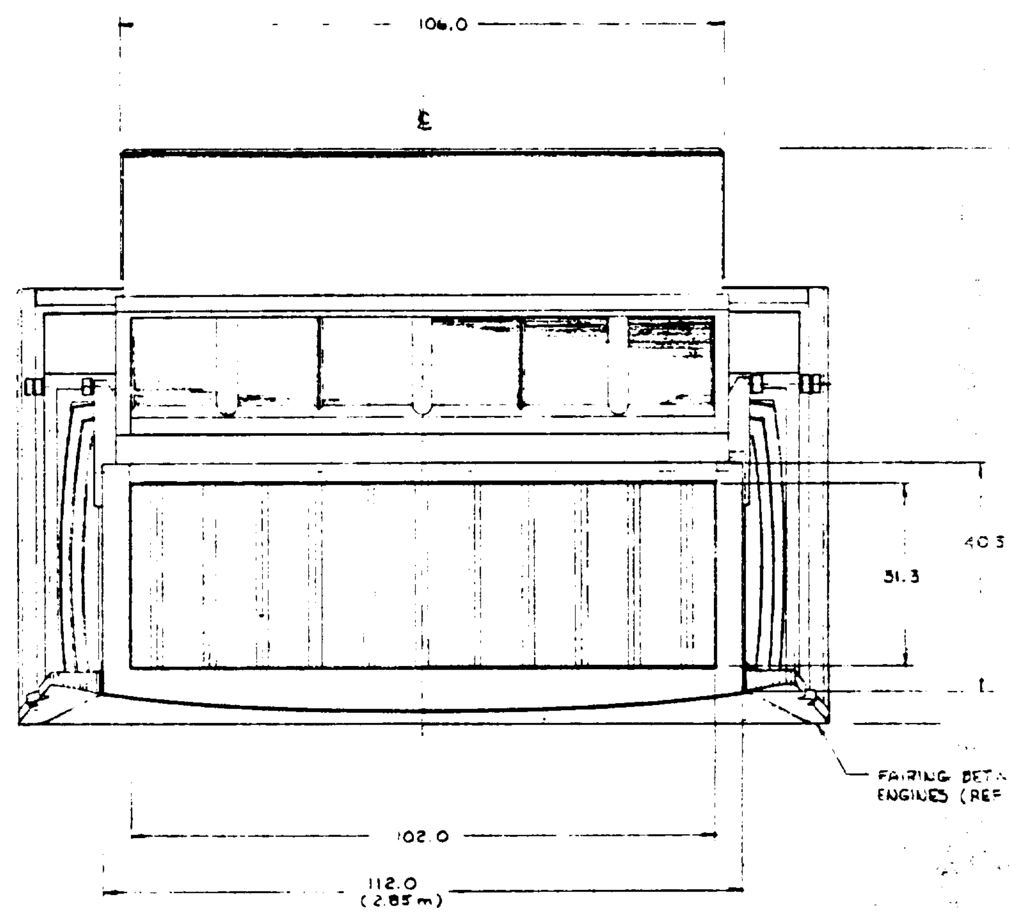

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107-1

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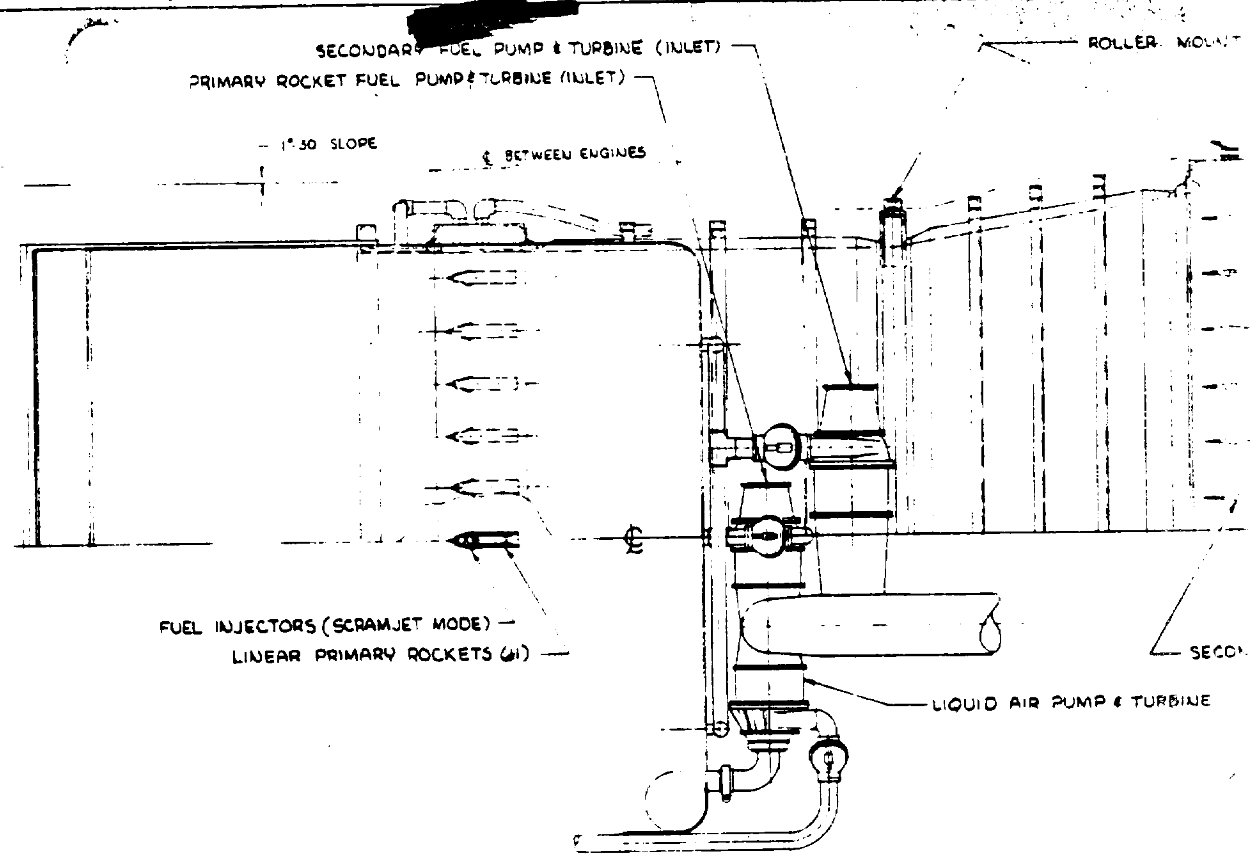
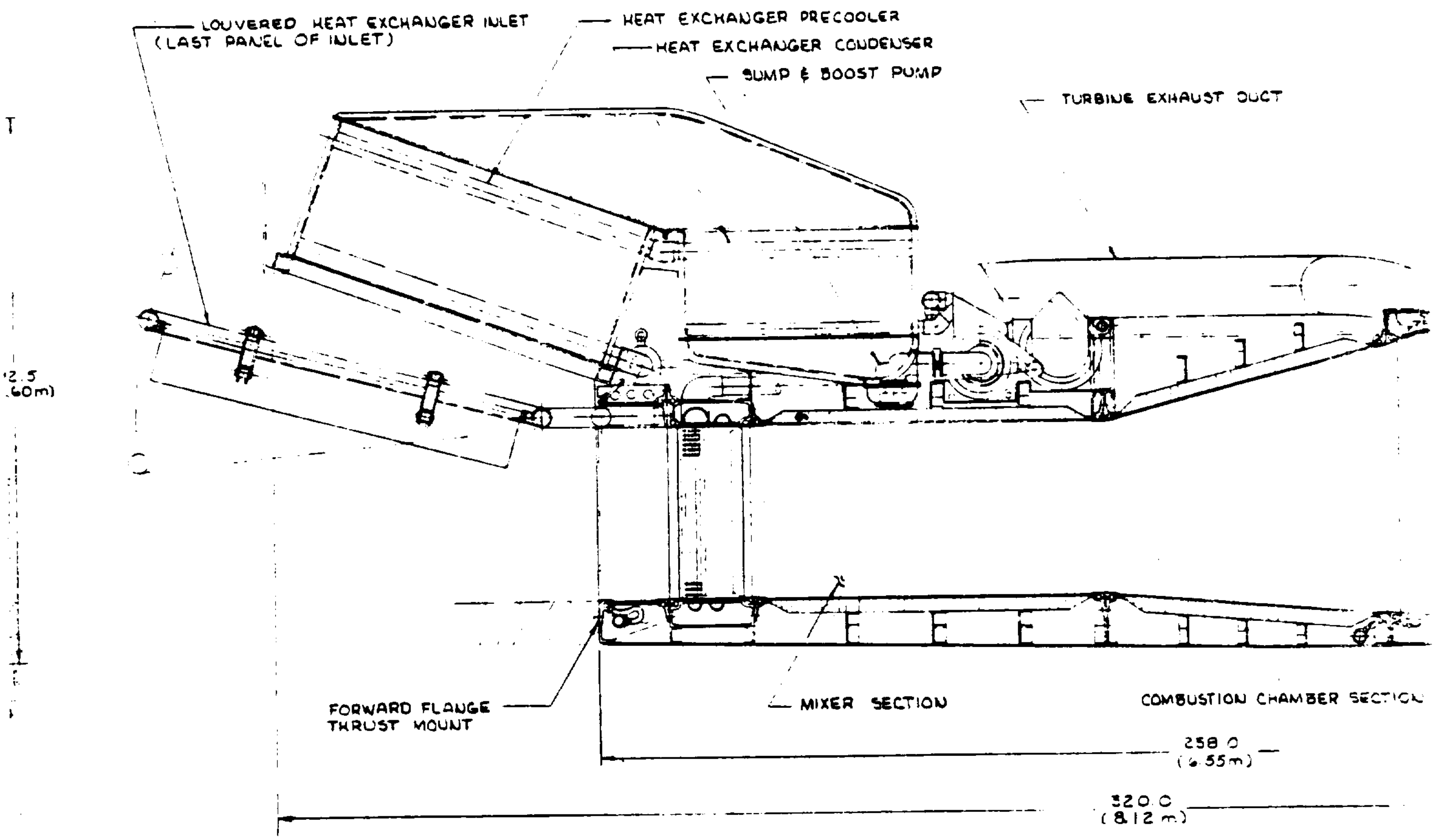
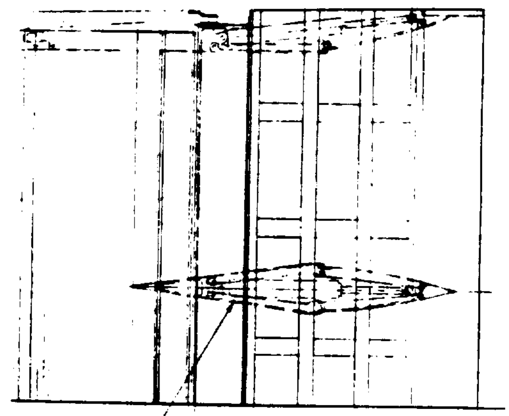


SECONDARY FUEL PUMP & TURBINE (INLET)
PRIMARY ROCKET FUEL PUMP & TURBINE (INLET)
ROLLER MOUNT
1°30 SLOPE
℄ BETWEEN ENGINES
℄
FUEL INJECTORS (SCRAMJET MODE)
LINEAR PRIMARY ROCKETS (61)
LIQUID AIR PUMP & TURBINE



LOUVERED HEAT EXCHANGER INLET
(LAST PANEL OF INLET)
HEAT EXCHANGER PRECOOLER
HEAT EXCHANGER CONDENSER
SUMP & BOOST PUMP
TURBINE EXHAUST DUCT
FORWARD FLANGE
THRUST MOUNT
MIXER SECTION
COMBUSTION CHAMBER SECTION
258.0
(6.55m)
320.0
(8.12 m)

(6)



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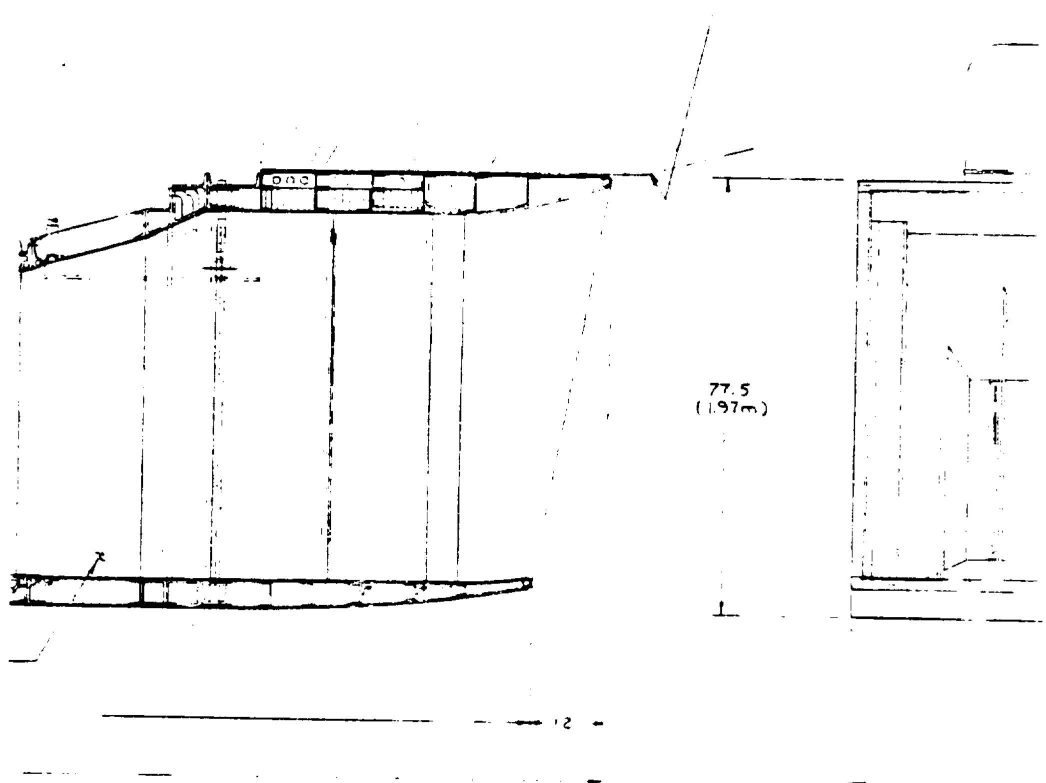

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DESIGN CHARACTERISTICS

1. MACH 12 FLIGHT SPEED CAPABILITY
2. THRUST SEA-LEVEL STATIC 173,000 LBF
3. PROPELLANTS: HYDROGEN (AUXILIARY OXYGEN)

DESIGN PARAMETERS

1. SECONDARY / PRIMARY MASS FLOW RATIO (SLS) 1.5
2. PRIMARY ROCKET CHAMBER PRESSURE 1000 PSIA
3. PRIMARY ROCKET O/F RATIO (ϕ=1.0) 34.3:1
4. MAXIMUM INTERNAL PRESSURE DESIGN 100 PSIA
5. SECONDARY AIR EQUIVALENCE RATIO, RAMJET : 1.0
6. HEAT EXCHANGER EQUIVALENCE RATIO : 8.0

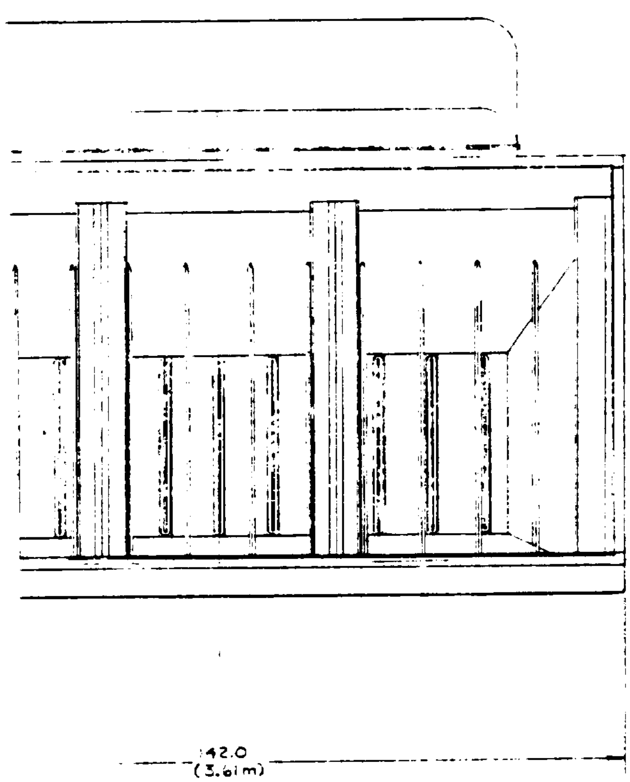
ENGINE FLOW AREAS

1. MIXER / COMBUSTOR (SUPERSONIC) A_3 = 22.89 SQ FT.
2. COMBUSTOR AFTERBURNER (SUBSONIC) A_4 = 47.87 SQ. FT.
3. NOZZLE THROAT, A_5
   MAXIMUM = A_4 = 47.87 SQ FT
   MINIMUM = 5 SQ. FT.
4. NOZZLE EXIT (MAX VEHICLE SURFACE), A_e = 274 SQ. FT.
5. AFTERBURNER / MIXER DIFFUSION RATIO A_4/A_3 = 2.1:1

OPERATION MODES

1. LIQUID AIR CYCLE EJECTOR MODE, MACH 0-3
2. SUBSONIC COMBUSTION RAMJET, MACH 3-6
3. SUPERSONIC COMBUSTION RAMJET MACH 6-12

[redacted]



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Note:

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CHECKED	SCRAM LACE ENGINE NO 22 NAS 7-377 CLASS 2 STUDY PHASE	
APPROVED ESCHER		
APPROVED		
	66845	R X 9057
	SCALE	SHEET OF

107-4

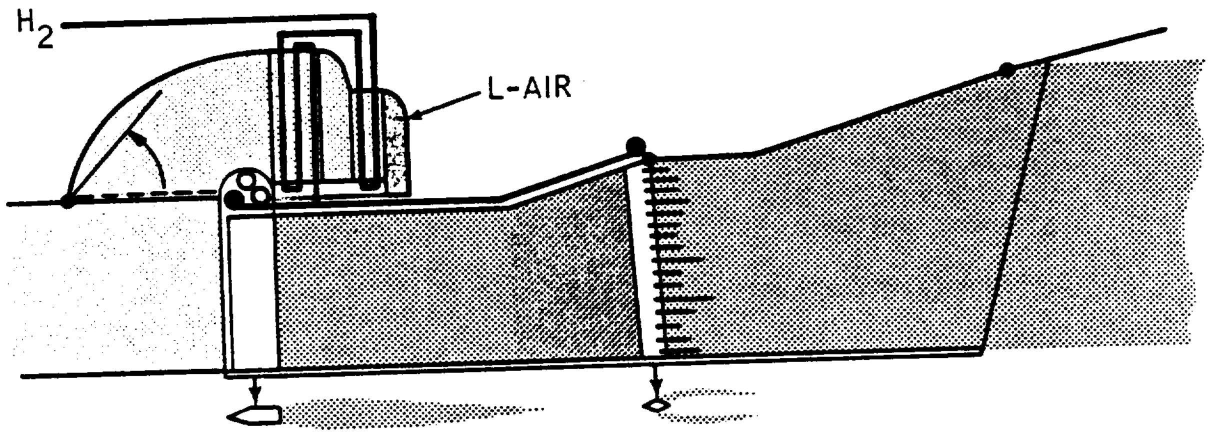
Eng. No. 22

WEIGHT STATEMENT - ENGINE NO. 22

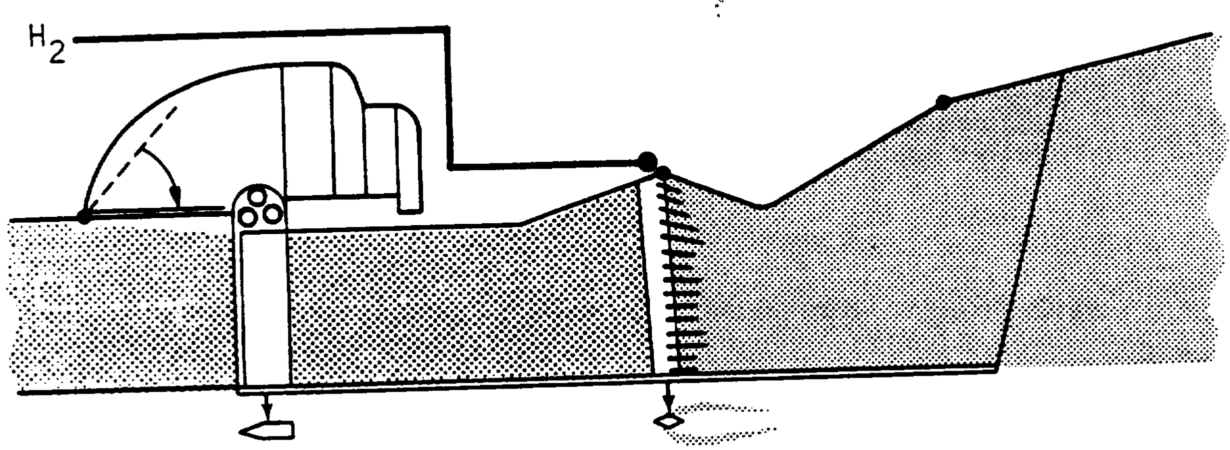
Air Liquefaction Subsystem		3561 lbm
Precooler Core	526	(34.1%)
Condenser Core	465	
Forward Shell	250	
Center Shell	284	
Aft Shell	130	
Sump	100	
Boost Pump, Ducting	307	
Catalyst (para/ortho)	969	
Closure and Transition	530	
Primary Rocket Subsystem		2334
Rocket Chamber Assembly	588	(22.3%)
Support Structure	1089	
Turbopumps	284	
Gas Generator Unit	149	
Ducting and Valves	76	
Starting System	148	
Mixer/Diffuser/Afterburner Subsystem		2252
Mixer	605	(21.5%)
Diffuser	585	
Fuel Injection Unit	460	
Combustion Chamber	495	
Miscellaneous	107	
Exit Nozzle Subsystem		2045
Moving Plate Exit Nozzle	1185	(19.6%)
Actuation Assembly	240	
Exit Nozzle	540	
Miscellanous (5%)	80	
Controls, Lines		265
Control Assemblies	80	(2.5%)
Valves and Lines	185	
Total Weight, Dry (Thrust = 173,000 lbf)		10,457 lbm (4743 kg)
Thrust/Weight, Uninstalled		16.5

SCRAMLACE (ENGINE NO. 22)

PROGRESSIVE OPERATING MODES
(PUMPING, COOLING AND CONTROL CIRCUITS NOT SHOWN)



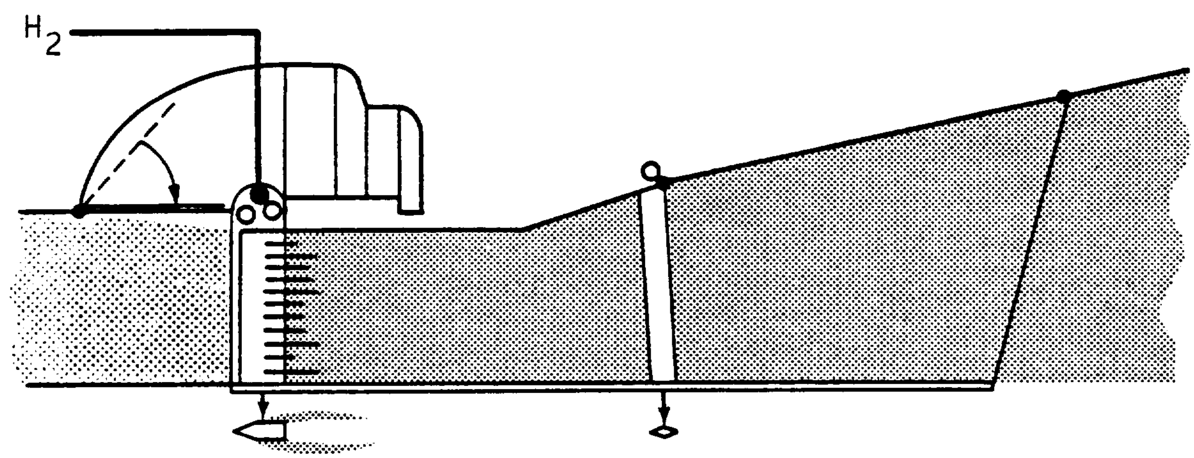
EJECTOR MODE



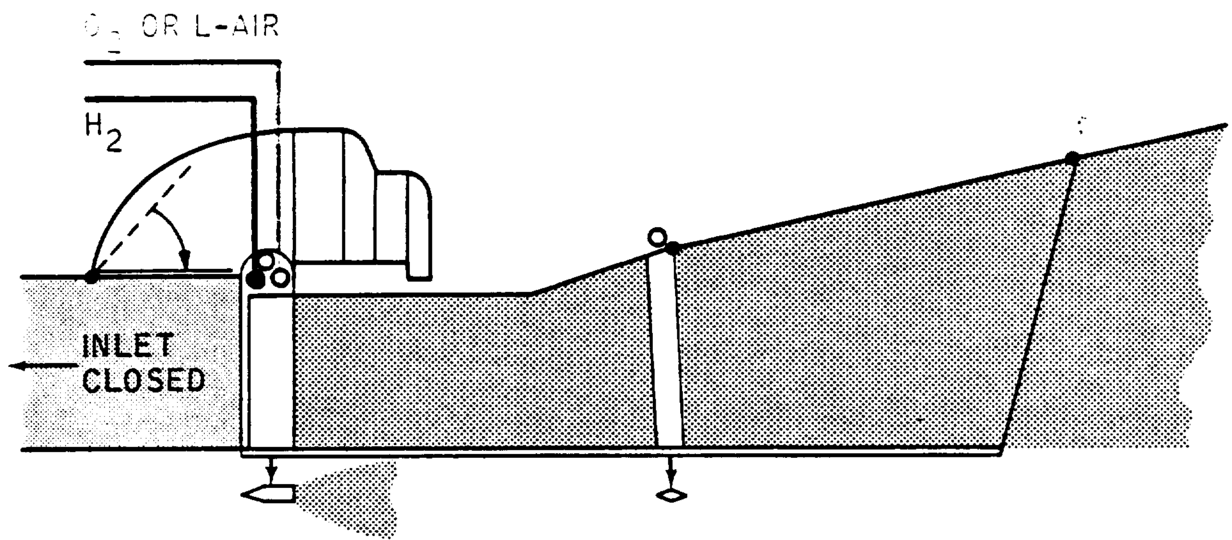
SUBSONIC COMBUSTION RAMJET MODE

SCRAMLACE (ENGINE NO. 22)

PROGRESSIVE OPERATING MODES
(PUMPING, COOLING AND CONTROL CIRCUITS NOT SHOWN)



SUPERSONIC COMBUSTION RAMJET MODE



ROCKET VACUUM MODE

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

Eng. No. 22

BASIC PROPELLANT CIRCUIT
SCRAMLACE, ENGINE NO. 22

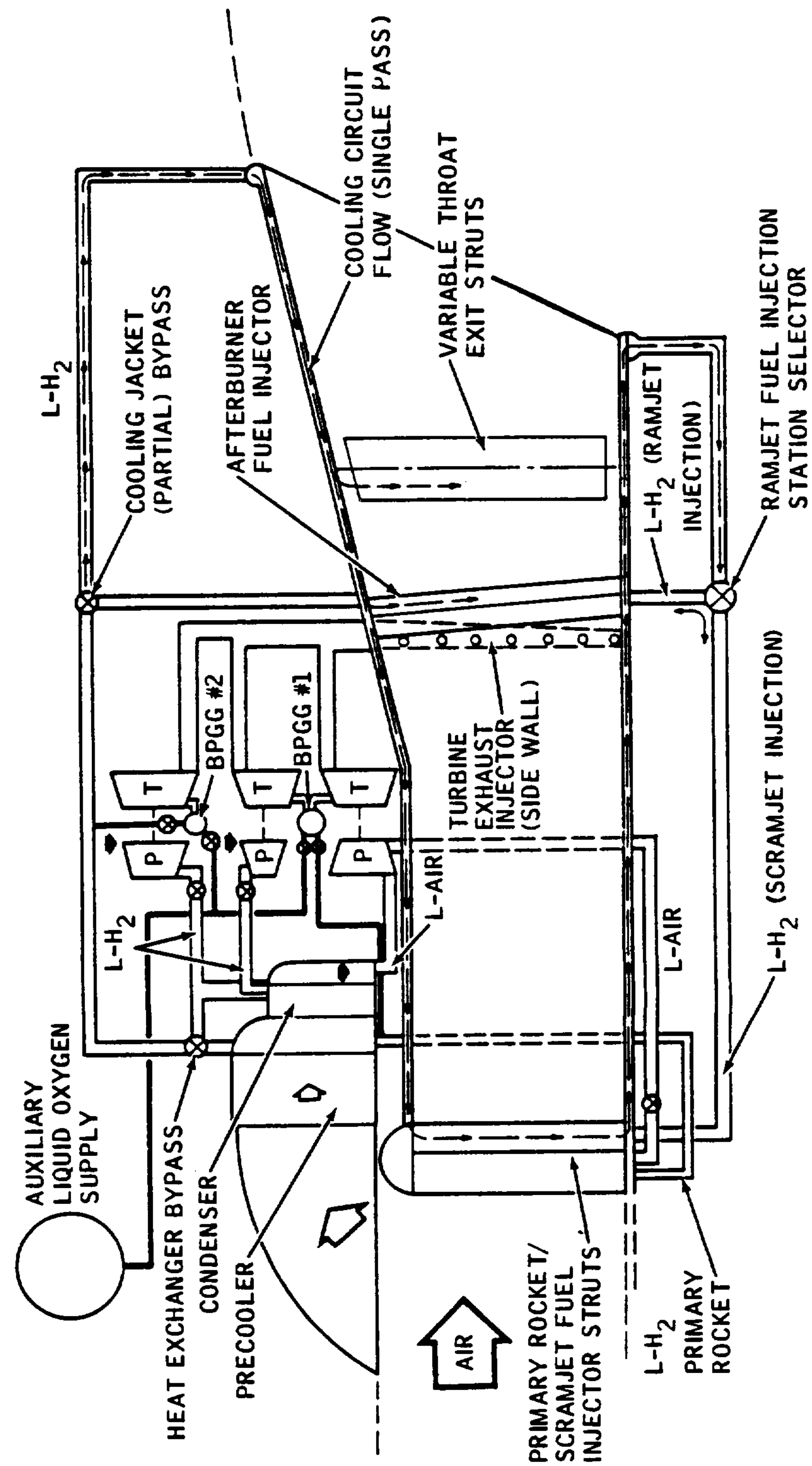
The propellant flow circuit including pumps and primary controls is reflected in the adjoining figure. The circuits shown are essentially for hydrogen fuel, the exception being the line from the liquid air condenser through the liquid air pump and to the primary rocket unit and the liquid oxygen auxiliary supply. The several valve junctures shown in the propellant circuitry are to accomodate bypass of fuel as appropriate for the individual operating modes.

Three turbopump assemblies are shown; one for liquid air, the remaining two for liquid hydrogen. Each pump is directly connected to its drive turbine. These are driven by bipropellant gas generators as shown. The lower set of pumps (figure) operates to provide propellants to the primary rocket and are driven by a common gas generator. The exhaust products of the gas generator are injected into the afterburner for further combustion of the fuel rich gases. A single gas generator is associated with the ramjet fuel pump which operates during the high speed modes following primary rocket shutdown. Fuel for the gas generators is self-pumped, with an auxiliary supply providing the oxidizer as shown.

All hydrogen, once pumped to pressure, passes through the condenser and the pre-cooler of the air liquefaction unit (in that order) prior to any other routing. A high pressure circuit of the order of 2000 psia conducts fuel through the heat exchanger and to the primary rocket assembly. Liquid air taken from the condenser is first pumped by an in-sump boost pump from which it goes to the suction connection of the high pressure liquid air pump. The pumped out liquid air is routed directly to the primary rocket chamber. A significantly higher flow of hydrogen is applied to the lower pressure circuit (1000 psia) which, after passing through the heat exchanger, is used for regenerative cooling of the entire engine. For the lower speed modes, the hydrogen coolant is collected and injected via the vertical fuel injection strips in the afterburner region. For supersonic combustion ramjet mode operation, the fuel is routed forward to the region of the primary rocket assembly where fuel injection takes place in the supersonic air stream. This shift is effected in order to accomplish combustion at the maximum contraction point in the engine.

Eng. No. 22

ENGINE NO. 22 - BASIC PROPELLANT SCHEMATIC



NOTE: BPGG - BIPROPELLANT GAS GENERATOR
⊗ - PROPELLANT VALVE

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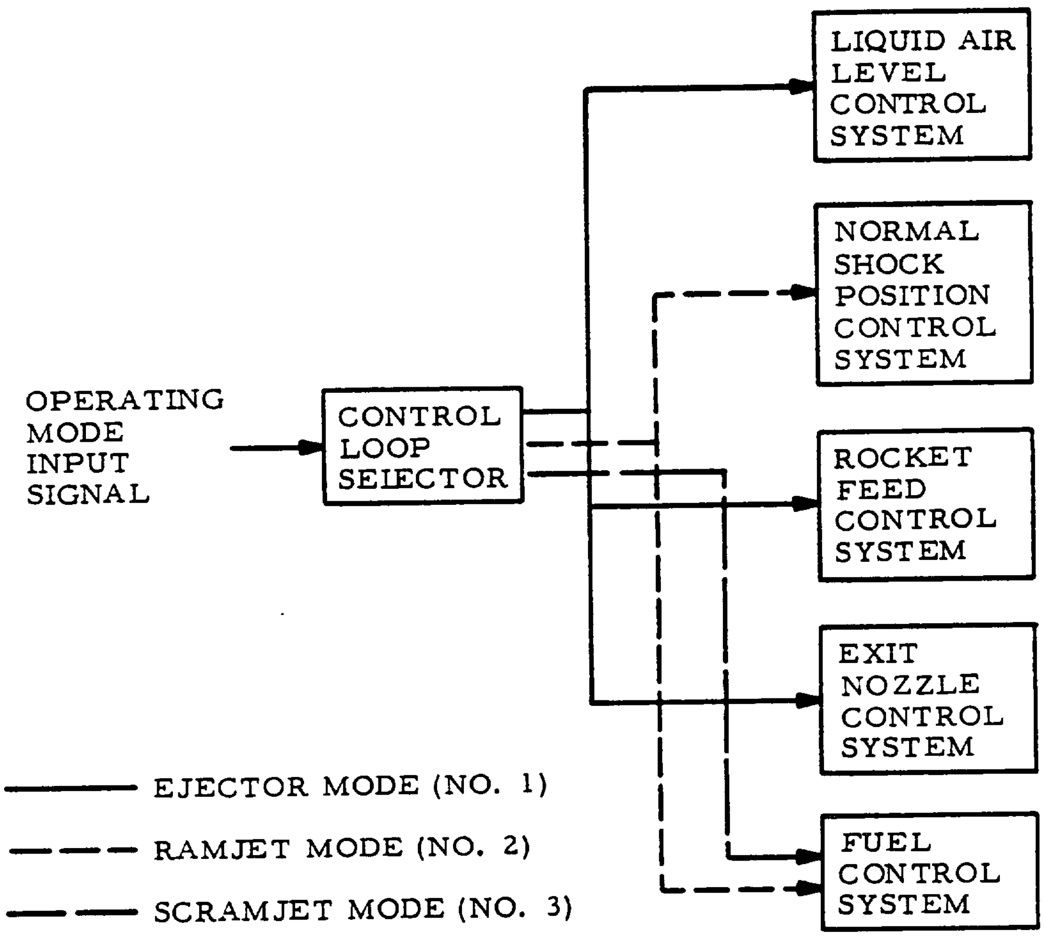
Eng. No. 22

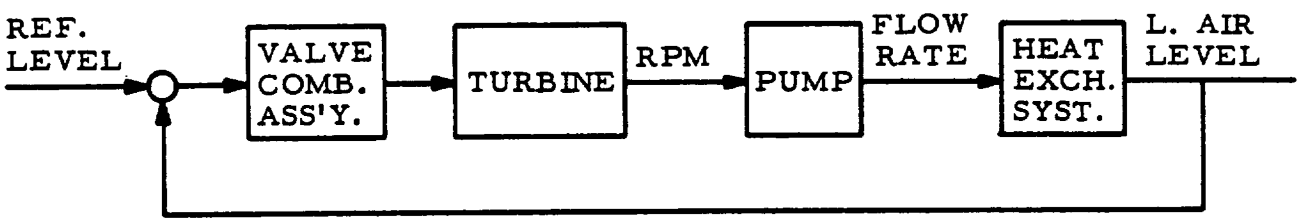
OPERATING MODE CONTROL SYSTEM

(BLOCK DIAGRAM)



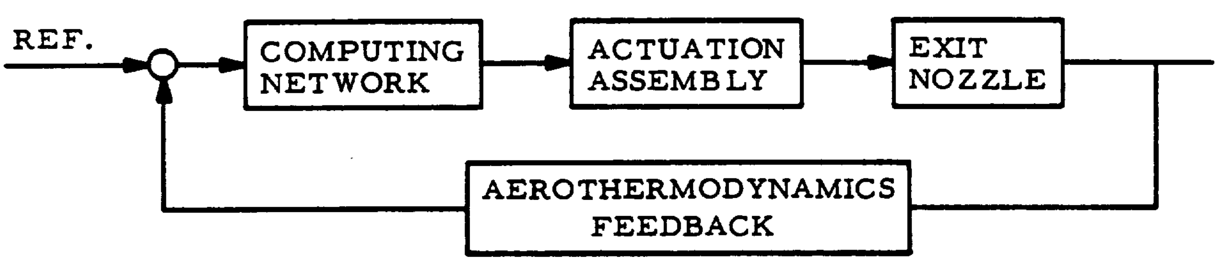
The engine is controlled by manual and/or automatic inputs for mode selection with several active control loops being used. Primary rocket control is based on a scheduled or pre-orificed system and has no active control as such. It is set to operate the system at a chamber pressure of 1000 psia and an air/fuel ratio of 34 to 1 (stoichiometric). An active loop controls the liquid air sump level. This is accomplished by proportional control of total hydrogen heat exchanger flow since this controls the air liquefaction rate. During the ejector mode the afterburner handles all of the excess hydrogen from the heat exchanger (fuel rich condition). During subsonic and supersonic combustion, ramjet mode, an active control establishes a nominal equivalence ratio of stoichiometric burning. This is accomplished by air and fuel mass flow sensing and consequent fuel control. The variable exit acccmplishes normal shock location in the inlet throat during supersonic flight speeds. The exit also operates in an over-ride loop to limit combustor pressure to the maximum design pressure of 100 psia.

LIQUID AIR LEVEL CONTROL SYSTEM



The liquid air level control system maintains the required liquid air level in the heat exchanger sump by controlling the flow of total liquid hydrogen through the heat exchanger, hence to the engine. The error signal which is generated by the difference between the required and actual level is employed to modulate the output of the gas generator controlling the speed of the turbine and pump. This results in flow modulation of liquid hydrogen through the heat exchanger to null the error, i.e., to adjust the air liquefaction rate to that being fed to the primary rocket.

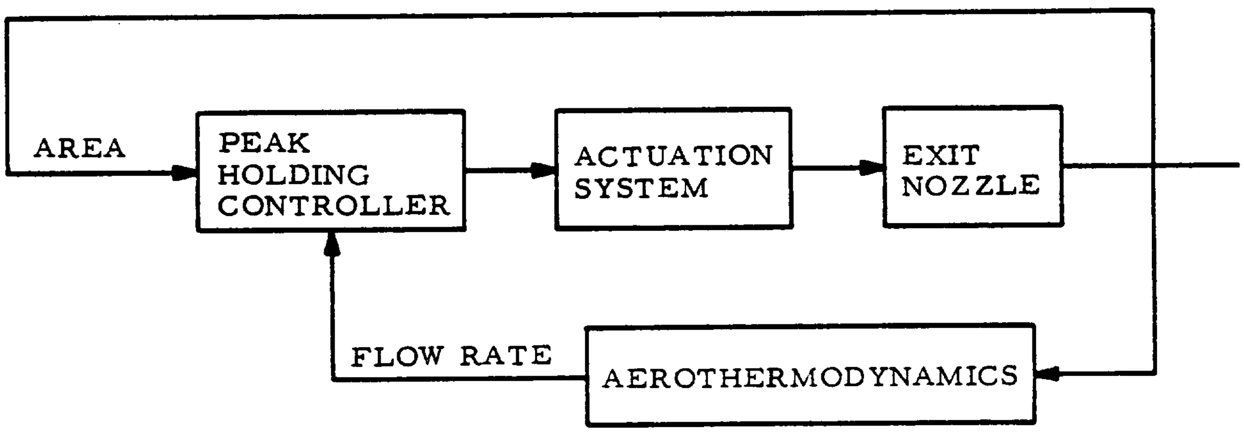
NORMAL SHOCK POSITION CONTROL SYSTEM
(EXIT NOZZLE MODULATION)



The normal shock position control system modulates the exit nozzle to position the normal shock in a predetermined optimum location, normally the inlet throat. Pressure signals indicative of the actual position of the shock are compared against a reference signal and the error is fed to a computing network which generates the required signal to the actuation system to null the error. The loop is closed by the aerothermodynamic feedback on the engine internal air flow.

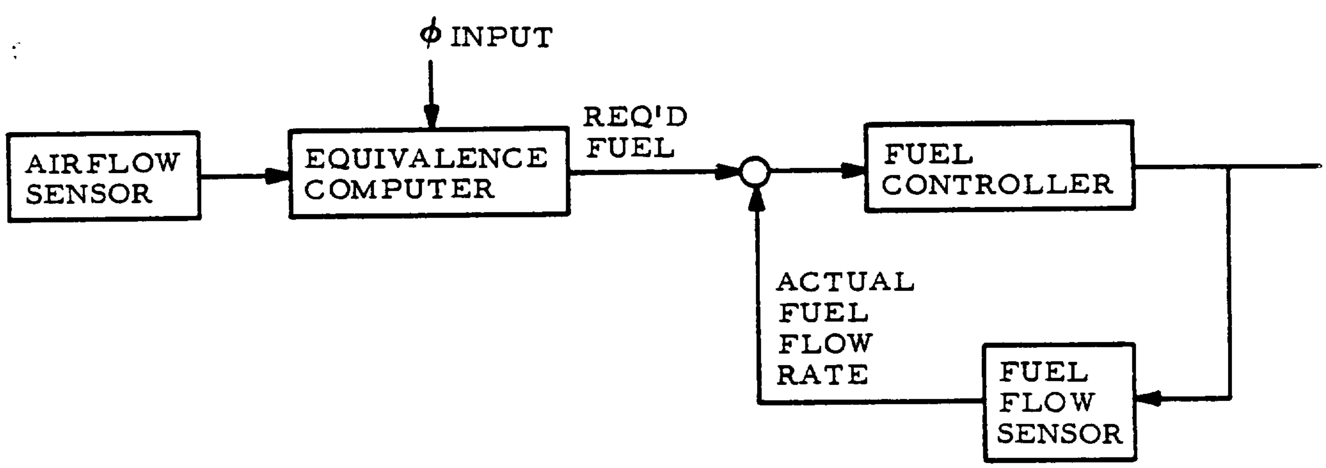
ROCKET FEED CONTROL SYSTEM

EXIT NOZZLE CONTROL SYSTEM



The exit nozzle control system is designed to maximize the combination of exit nozzle area and air flow rate by modulating the exit nozzle throat area. A signal proportional to air flow rate and exit nozzle area is introduced at the peak holding controller which signals the actuation system to modulate the exit nozzle actuator to maximize, or peak, the product of throat area and air flow rate.

FUEL CONTROL SYSTEM



The fuel control system is a closed loop control system which senses the air flow rate through the engine and modulates the fuel flow rate to maintain a required fuel air ratio (ϕ). A signal proportional to air flow is applied at the equivalence computer which generates a command for the required fuel flow rate. This signal is compared against a fuel flow rate feedback signal generating the error signal which is applied at the fuel controller. The fuel controller will then modulate the fuel flow until the error is nulled.

VEHICLE DESIGN - SCRAMLACE, ENGINE NO. 22

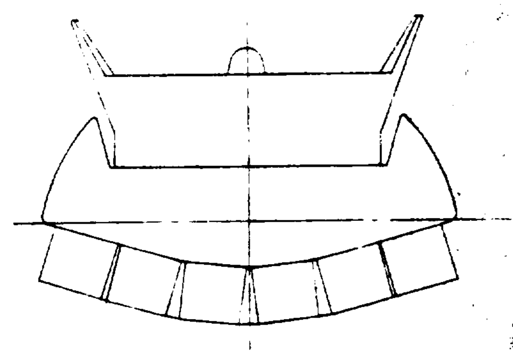
This figure shows the final Class 2 vehicle design utilizing ScramLACE engines. This lifting body vehicle was determined to be substantially superior in performance to the other vehicle types considered. The lifting body shown features high slenderness ratio, elimination of the second stage base drag through submergence, and attainment of stabilizing surface at low unit weight. The vehicle incorporates an aft hydrogen tank and a propulsion package consisting of six engine modules of 173,000-lb thrust each (1.038 T/W), with a 408-ft^2 total capture area. A vehicle affixed nozzle contour is effected to accommodate the supersonic combustion mode. The system second-stage gross weight is 397,573 pounds for Mach 10 cut-off conditions (payload maximum).

The lifting-body configuration employs a modified conical fuselage where the forebody is a blunted cone with a depth-to-width ratio of 0.4 at any station. Maximum cross section of the fuselage is at 73 percent of the body length, as measured from the virtual nose (apex). The fuselage nose radius is one foot, and the body planform area is 13,612 ft^2.

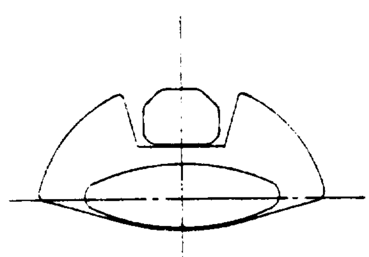
The horizontal stabilizer has a leading edge sweep of 65 degrees, and an area of 2612 ft^2. The airfoil section is double wedge, with a two-inch leading edge radius. The movable horizontal control surfaces comprise 2000 ft^2. The horizontal control surface rotates against the vertical stabilizer with forward extending dorsal fins, to alleviate the thermal problem associated with the sharp edges of the control surface under high-speed deflection conditions.

The twin vertical stabilizers have a total exposed area of 1200 ft^2, with a leading edge radius of two inches. No toe-in is provided for the verticals, rather, a concept of utilizing small outward rudder deflections to load the surfaces during hypersonic operation where the control surface lift curve slope is zero at zero deflection is proposed, in order to maintain minimum vehicle drag. All panel surfaces have a thickness ratio of 5 percent.

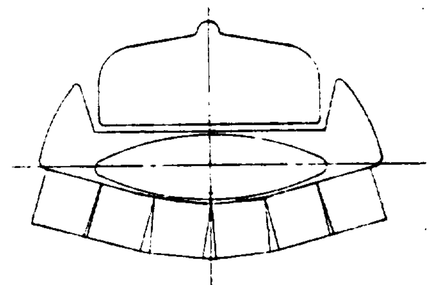
[redacted]



SECTION **C - C**



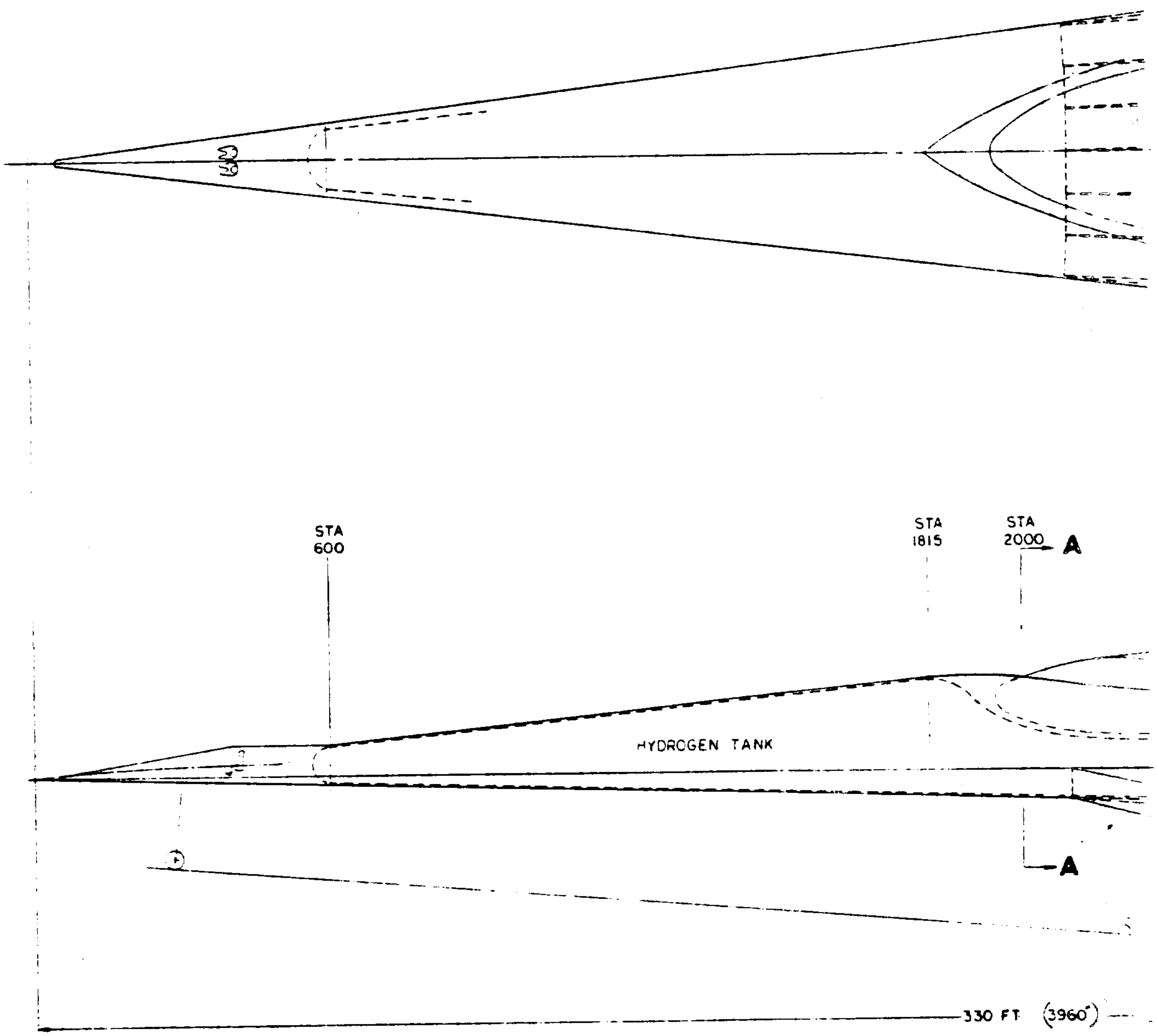
SECTION **A - A**



SECTION **B - B**

[redacted]

[redacted]



[redacted]

117-2

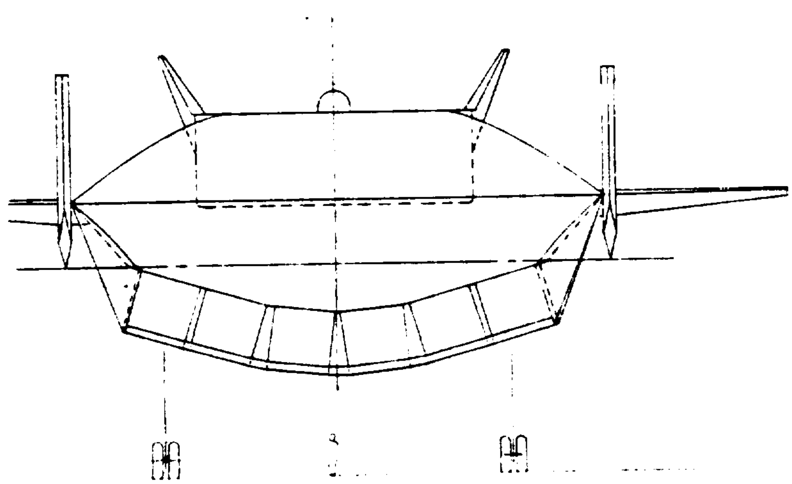
[redacted]

BODY PLANFORM AREA	13612 FT^2
HORIZ STAB. AREA	2000 FT^2
STUB WING AREA	612 FT^2
TOTAL PLANFORM AREA	16224 FT^2

VERTICAL FIN AREA 1200 FT^2

A_c 408.5 FT^2

T/W_{SLS} 1.035



[redacted]

[illegible] CRAFT ENGINEERING

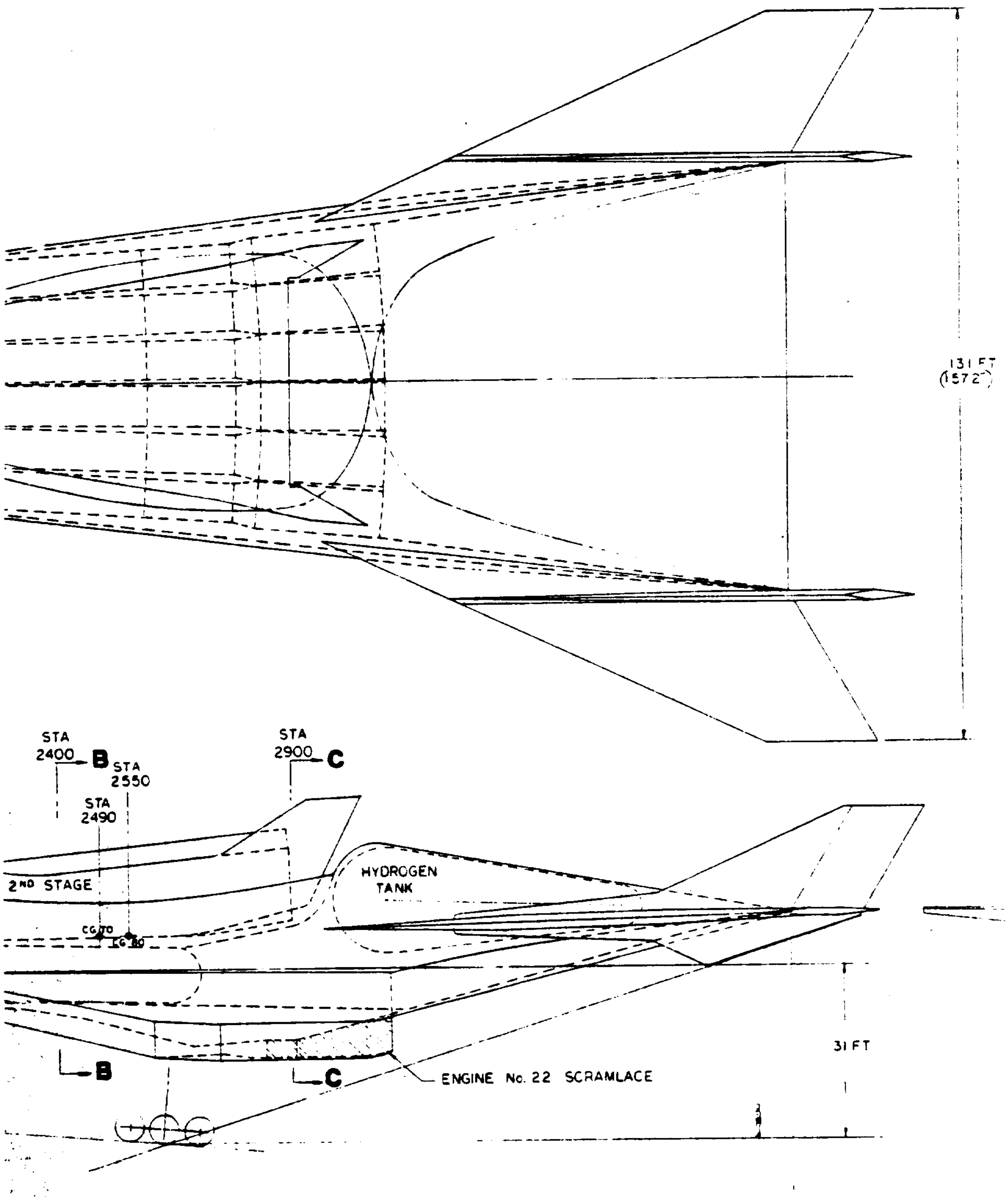
CLASS 2 - SYSTEM No 22
SCRAMLACE

[illegible signature] 1-21-66
[illegible signature]

CL655-1-18A

[redacted]

[redacted]



[redacted]

[redacted]

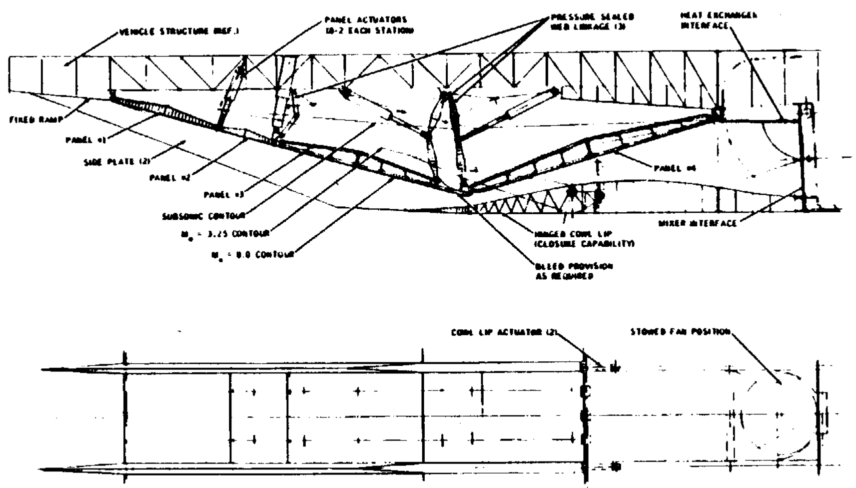
117-3

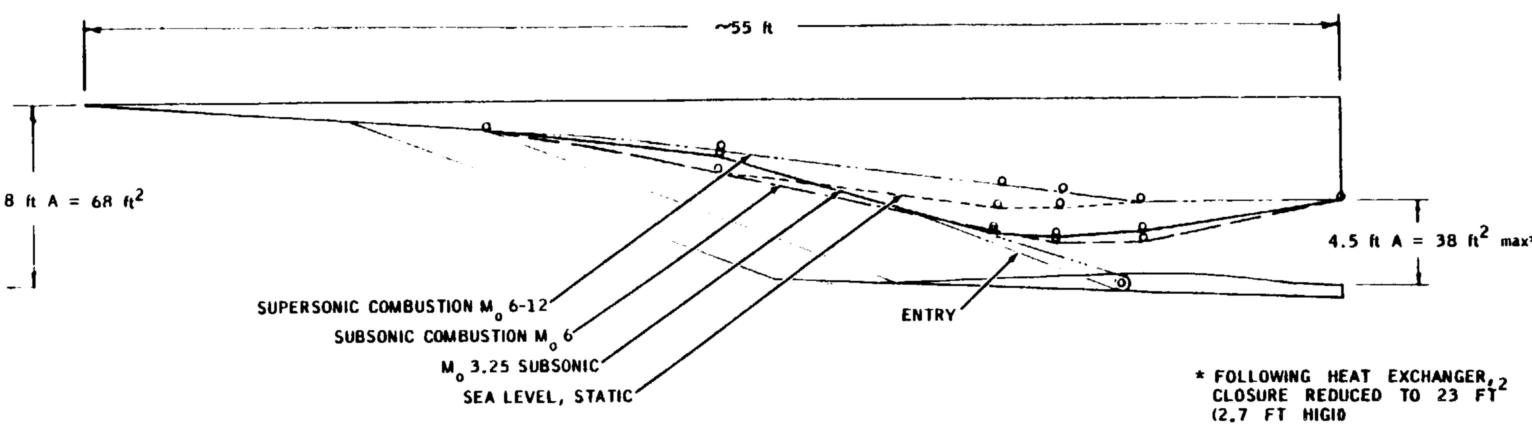
Eng. No. 22

INLET CONTOUR - MACH 0 - 12 CAPABILITY

R-21,735

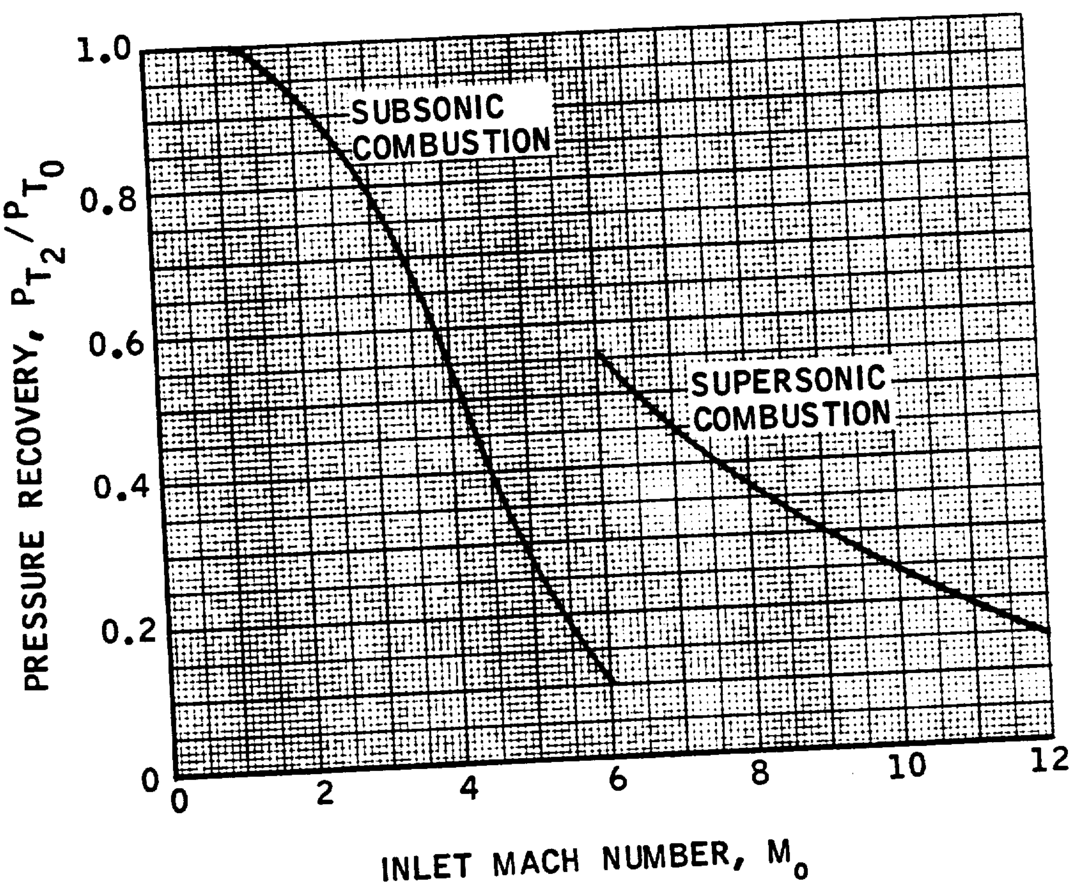
MECHANIZATION OF TWO-DIMENSIONAL, MOVING PANEL INLET
(MACH 8 CAPABILITY ENGINES, TYPICAL)



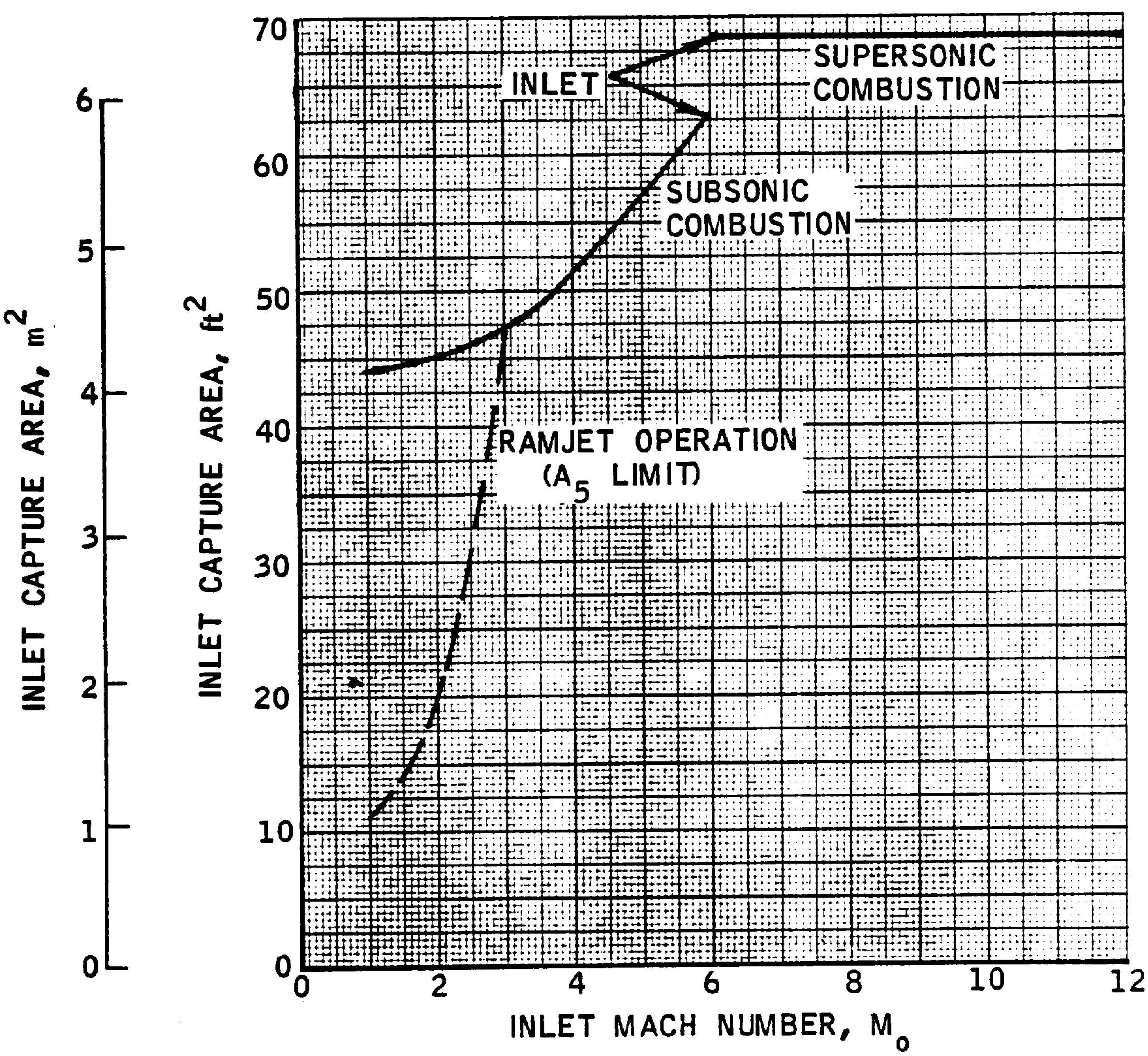


* FOLLOWING HEAT EXCHANGER, CLOSURE REDUCED TO 23 FT^2 (2.7 FT HIGH)

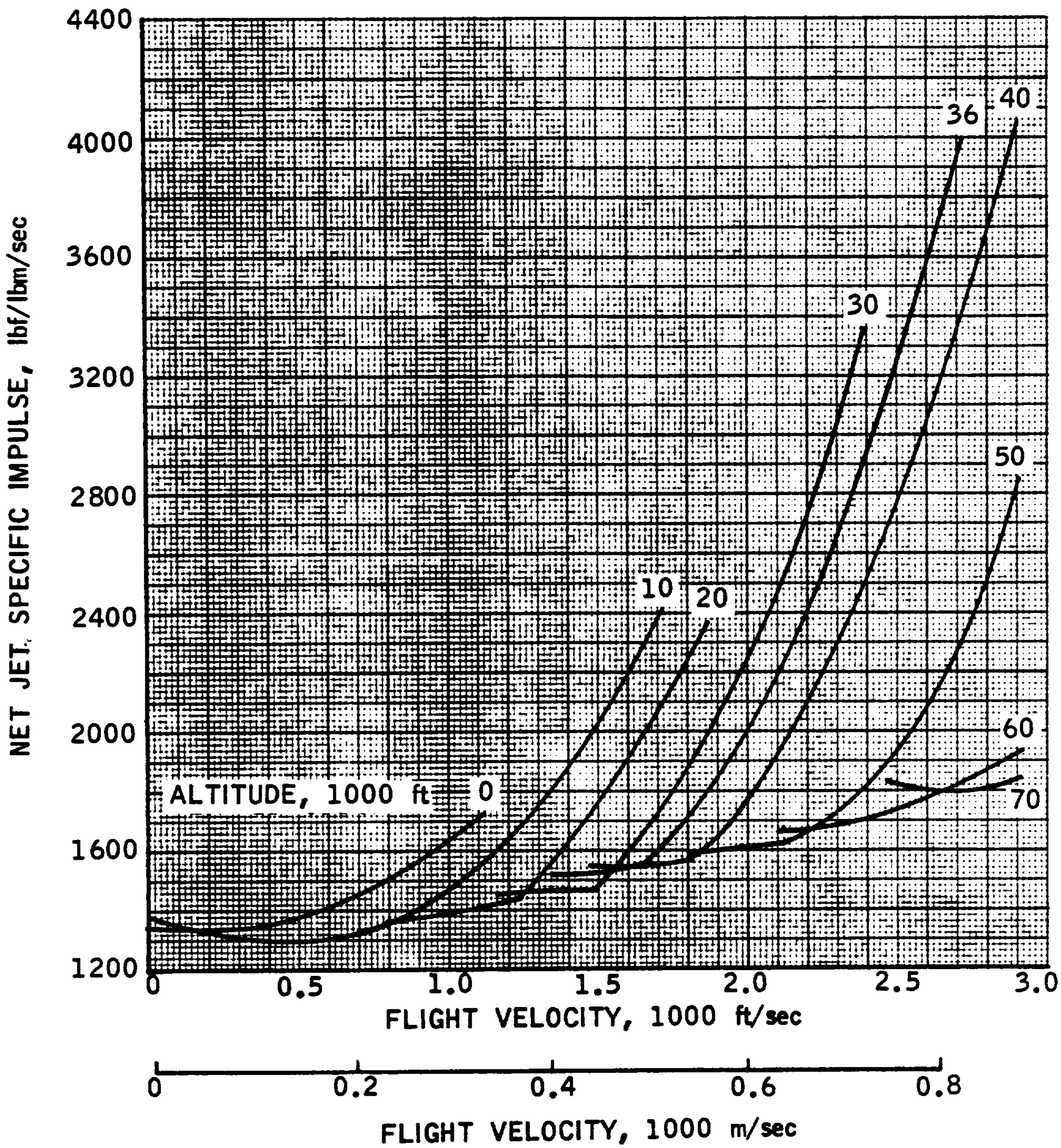
INLET PRESSURE RECOVERY



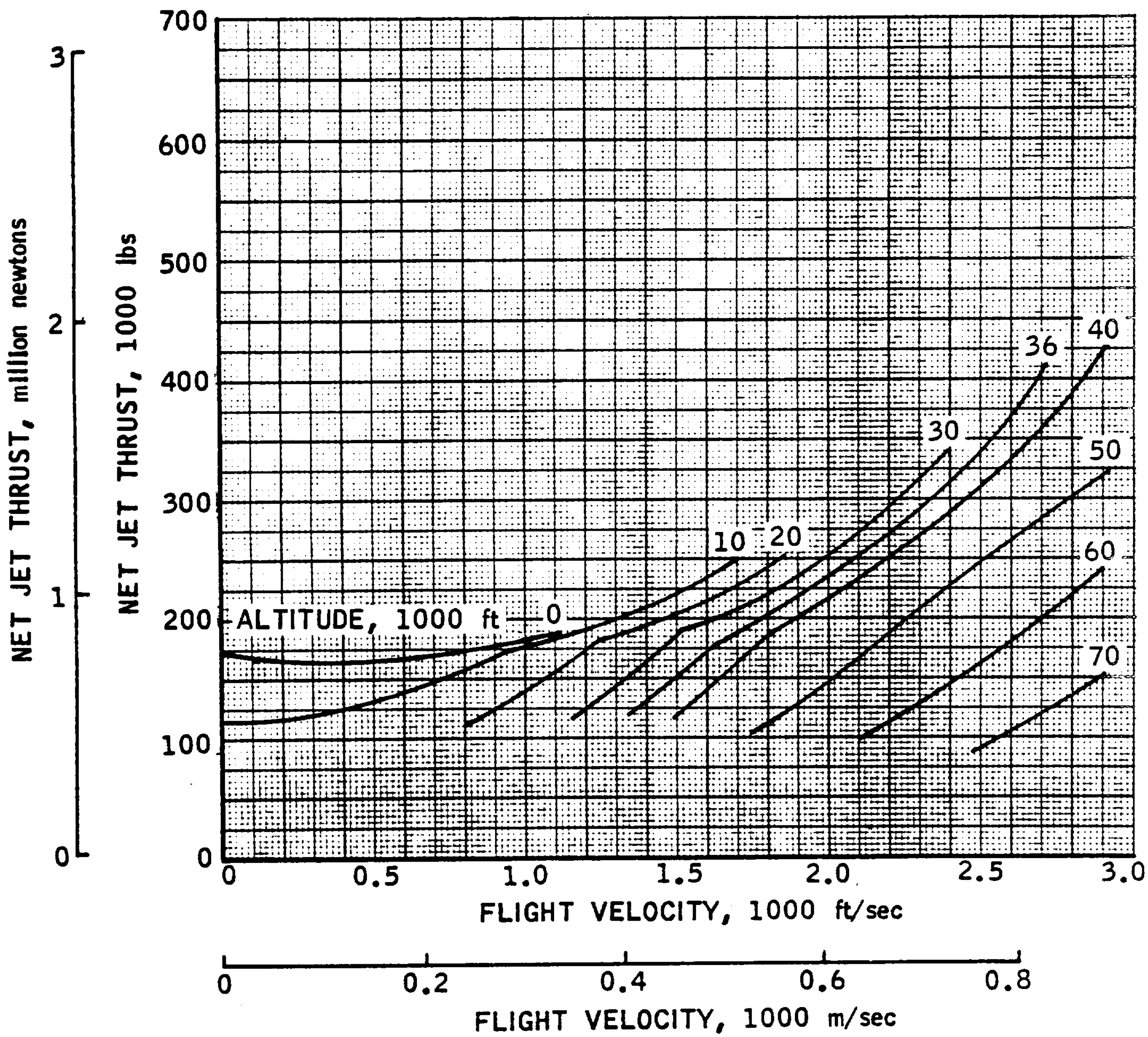
INLET CAPTURE AREA



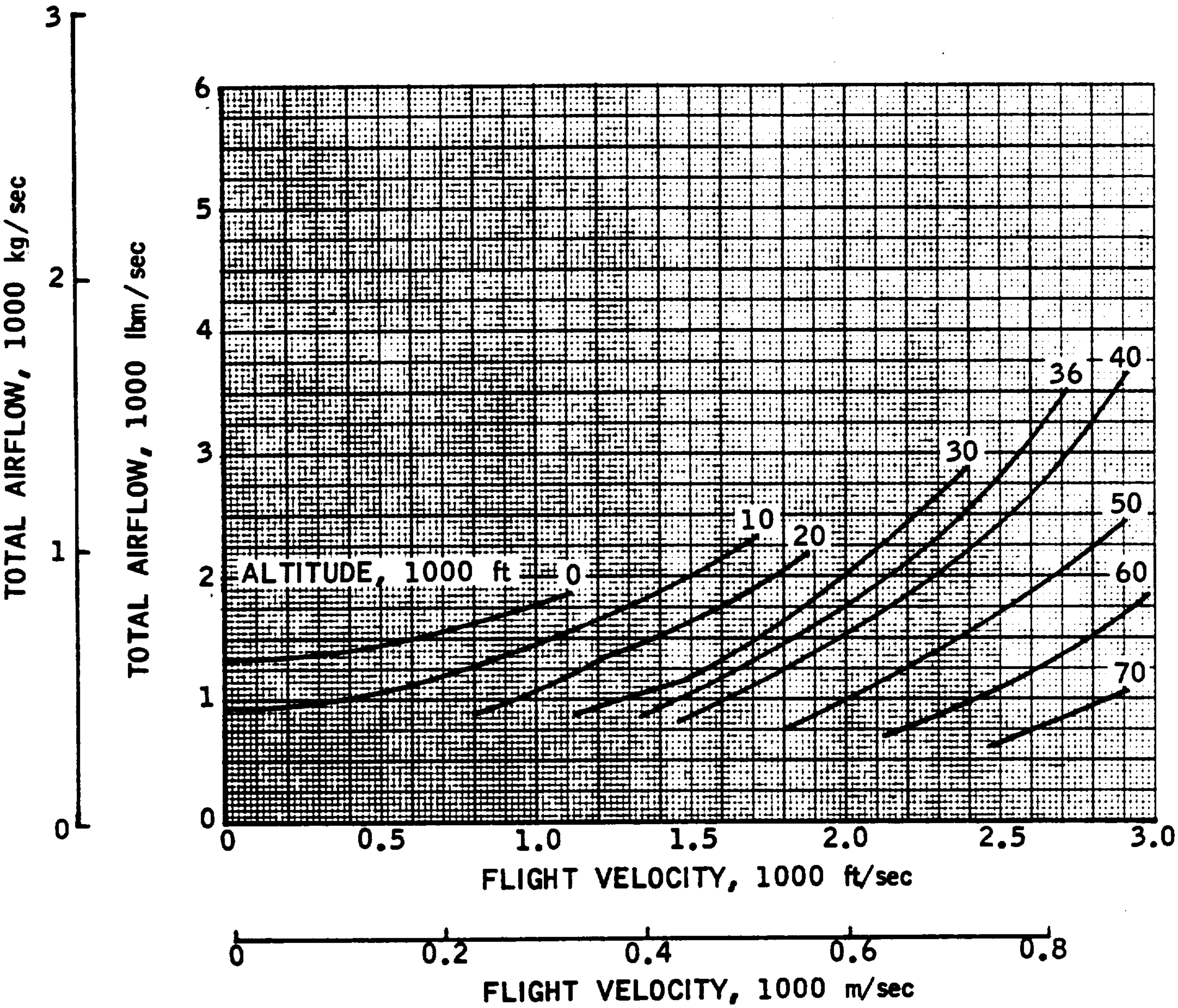
EJECTOR MODE SPECIFIC IMPULSE



EJECTOR MODE THRUST



EJECTOR MODE AIRFLOW



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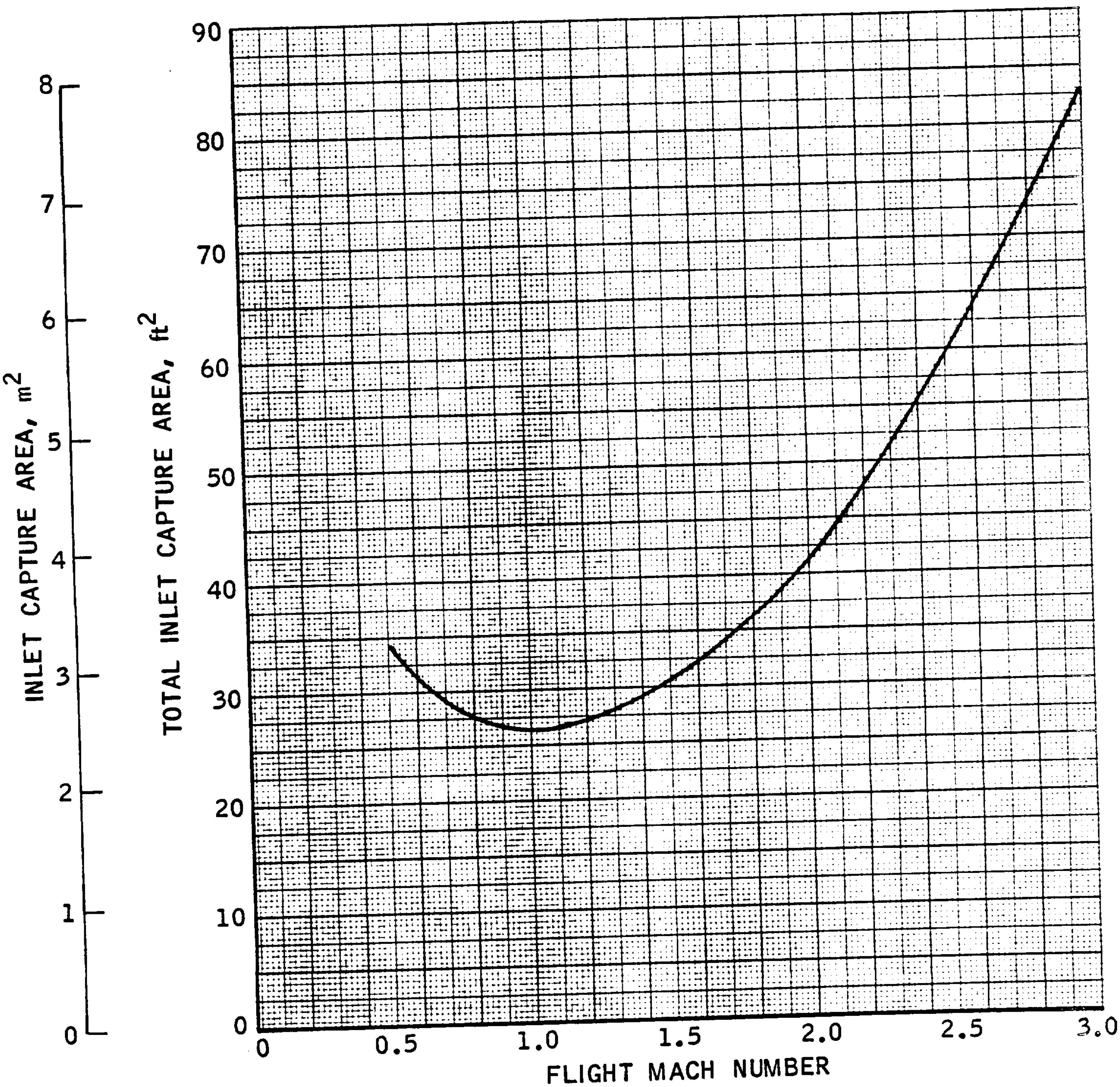
THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

Eng. No. 22

EJECTOR MODE CAPTURE AREA

NOTE: 1. CURVE REFLECTS UPPER LIMIT.
2. EJECTOR MODE CAPTURE AREA CAN EXCEED NOMINAL INLET SIZE (SEE SUPPLEMENTARY TABULAR DATA).



[redacted]

ENGINE- 22 CLASS 2

ESTIMATED PERFORMANCE

MU	VO	HTO	PTO	T	CF	IS	SPC	PT2	H2	P2
				ALTITUDE -	0. FEET					
0.01	11.	124.5	14.7	173087.	750.27	1344.	2.68	14.70	113.3	10.59
0.25	279.	126.0	15.3	165912.	28.11	1338.	2.69	15.35	114.7	11.06
0.50	558.	130.7	17.4	166550.	13.17	1396.	2.58	17.43	119.0	12.57
0.75	837.	138.5	21.3	175701.	8.26	1533.	2.35	21.34	126.2	15.41
1.00	1116.	149.4	27.8	190824.	5.89	1725.	2.09	27.82	137.9	21.02
				ALTITUDE -	10000. FEET					
[redacted].01	11.	115.1	10.1	115797.	757.22	1384.	2.60	10.11	104.7	7.28
[redacted].30	322.	117.1	10.8	120715.	24.57	1313.	2.74	10.76	106.6	7.75
[redacted]0.60	644.	123.4	12.9	140941.	12.28	1314.	2.74	12.89	112.3	9.29
[redacted]0.90	966.	133.7	17.1	176500.	8.22	1432.	2.51	17.10	121.8	12.32
1.20	1288.	148.2	24.5	201470.	5.75	1758.	2.05	24.33	135.0	17.54
1.40	1503.	160.2	32.2	221508.	4.77	2016.	1.79	31.51	148.2	23.94
1.60	1718.	174.0	43.0	254104.	4.08	2417.	1.49	41.36	161.8	32.00
				ALTITUDE -	20000. FEET					
0.77	801.	120.2	10.0	113214.	10.14	1363.	2.64	10.02	109.4	7.22
1.00	1037.	128.9	12.8	145107.	8.10	1398.	2.57	12.79	117.3	9.22
1.20	1244.	138.3	16.4	183580.	6.92	1452.	2.48	16.27	126.0	11.73
1.50	1555.	155.7	24.8	213850.	5.17	1841.	1.96	24.10	141.9	17.38
1.80	1867.	177.0	38.8	256252.	4.08	2367.	1.52	36.70	163.3	27.61

ENGINE- 22 CLASS 2

ESTIMATED PERFORMANCE

M2	WS	WP	WSWP	WFT	PHP	PHS	V6	PT20	A0	A5	A6
ALTITUDE - 0. FEET											
0.700	810.	535.	1.51	128.8	1.0	4.492	3848.	1.00	949.62	42.25	44.68
0.700	841.	535.	1.57	124.0	1.0	4.142	3871.	1.00	39.43	42.58	45.14
0.700	938.	535.	1.75	119.3	1.0	3.546	3932.	1.00	21.99	43.99	46.98
0.698	1115.	535.	2.08	114.6	1.0	2.843	4030.	1.00	17.41	46.38	50.25
0.646	1348.	535.	2.52	110.6	1.0	2.256	4172.	1.00	15.77	47.83	53.35
ALTITUDE - 10000. FEET											
0.700	579.	348.	1.66	83.7	1.0	4.085	3752.	1.00	949.50	43.82	45.95
0.700	611.	382.	1.60	91.9	1.0	4.253	3931.	1.00	33.39	43.05	46.04
0.700	714.	446.	1.60	107.3	1.0	4.247	4227.	1.00	19.50	42.96	48.12
0.700	910.	535.	1.70	123.2	1.0	3.799	4568.	1.00	16.56	43.48	52.61
0.700	1231.	535.	2.30	114.6	1.0	2.575	4701.	0.99	16.79	47.64	60.20
0.640	1468.	535.	2.75	109.9	1.0	2.053	4837.	0.98	17.14	47.73	63.76
0.618	1816.	535.	3.40	105.1	1.0	1.574	5006.	0.96	18.52	47.76	68.97
ALTITUDE - 20000. FEET											
0.700	562.	345.	1.63	83.0	1.0	4.176	4471.	1.00	17.24	43.06	50.99
0.700	693.	431.	1.61	103.8	1.0	4.229	4812.	1.00	16.41	42.66	55.64
0.700	852.	535.	1.59	126.4	1.0	4.181	5108.	0.99	16.78	42.27	61.30
0.700	1191.	535.	2.23	116.2	1.0	2.705	5243.	0.97	18.75	46.47	71.65
0.652	1646.	535.	3.08	108.3	1.0	1.800	5420.	0.94	21.55	47.76	82.41

ENGINE- 22 CLASS 2

ESTIMATED PERFORMANCE

MU	VO	HTO	PTO	T	CF	IS	SPC	PT2	H2	P2
ALTITUDE - 30000. FEET										
1.17	1160.	125.7	10.1	118728.	7.48	1464.	2.46	10.09	114.5	7.27
1.30	1293.	132.2	12.1	142776.	6.89	1471.	2.45	11.96	120.4	8.62
1.40	1393.	137.6	13.9	161813.	6.47	1484.	2.43	13.63	125.3	9.83
1.50	1492.	143.3	16.1	189221.	6.17	1470.	2.45	15.59	130.6	11.24
1.90	1890.	170.2	29.3	237993.	4.46	2049.	1.76	27.41	155.2	19.78
2.40	2388.	212.7	63.9	345560.	3.25	3337.	1.08	56.48	195.9	42.04
ALTITUDE - 36000. FEET										
1.39	1345.	129.8	10.3	121555.	6.69	1523.	2.36	10.14	118.2	7.31
1.50	1453.	135.9	12.1	144072.	6.34	1512.	2.38	11.79	123.8	8.50
1.60	1550.	141.7	14.1	162006.	5.97	1535.	2.35	13.53	129.1	9.75
1.70	1647.	147.9	16.3	183594.	5.66	1550.	2.32	15.57	134.7	11.23
2.00	1938.	168.7	25.9	230126.	4.61	1904.	1.89	23.94	153.8	17.27
2.40	2325.	201.7	48.3	302888.	3.55	2718.	1.32	42.70	184.8	31.28
2.80	2713.	240.7	89.7	418044.	2.81	3976.	0.91	74.92	220.0	54.19
ALTITUDE - 40000. FEET										
1.52	1470.	136.7	10.3	120280.	6.25	1531.	2.35	9.98	124.5	7.19
1.65	1597.	144.6	12.5	142712.	5.83	1546.	2.33	11.98	131.7	8.64
1.85	1791.	157.7	16.9	185343.	5.28	1565.	2.30	15.93	143.7	11.49
2.00	1936.	168.5	21.4	211876.	4.82	1676.	2.15	19.77	153.6	14.26
2.50	2420.	210.6	46.6	295392.	3.48	2596.	1.39	40.66	192.3	29.38
3.00	2904.	262.1	100.3	429921.	2.61	4029.	0.89	81.17	239.7	58.74

ENGINE- 22 CLASS 2

ESTIMATED PERFORMANCE

M2	WS	WP	WSWP	WFT	PHP	PHS	V6	PT20	A0	A5	A6
ALTITUDE - 30000. FEET											
0.700	553.	337.	1.64	81.1	1.0	4.144	5059.	0.99	16.65	42.81	61.34
0.700	640.	403.	1.59	97.1	1.0	4.287	5278.	0.99	17.27	42.13	66.13
0.700	716.	453.	1.58	109.1	1.0	4.307	5416.	0.98	17.93	41.97	70.23
0.700	802.	535.	1.50	128.8	1.0	4.535	5585.	0.97	18.75	41.20	75.17
0.700	1297.	535.	2.43	116.2	1.0	2.484	5758.	0.94	23.88	46.64	94.95
0.666	2345.	535.	4.38	103.6	1.0	1.197	6064.	0.88	34.04	47.77	127.53
ALTITUDE - 36000. FEET											
[redacted].700	548.	332.	1.65	79.8	1.0	4.118	5376.	0.98	17.84	42.65	70.43
[redacted].700	622.	396.	1.57	95.3	1.0	4.325	5561.	0.97	18.75	41.72	75.74
[redacted].700	700.	439.	1.60	105.6	1.0	4.262	5678.	0.96	19.75	41.84	80.90
[redacted].700	789.	492.	1.60	118.5	1.0	4.244	5799.	0.95	20.94	41.83	86.73
[redacted].700	1138.	535.	2.13	120.9	1.0	2.968	5993.	0.93	25.64	45.05	104.88
0.684	1842.	535.	3.44	111.4	1.0	1.664	6177.	0.88	34.49	47.84	134.61
0.700	3004.	535.	5.62	105.1	1.0	0.952	6352.	0.84	48.03	46.78	173.09
ALTITUDE - 40000. FEET											
0.700	525.	326.	1.61	78.5	1.0	4.225	5574.	0.97	18.92	41.76	76.32
0.700	614.	384.	1.60	92.3	1.0	4.250	5746.	0.96	20.32	41.50	83.47
0.700	782.	492.	1.59	118.5	1.0	4.278	5992.	0.94	23.08	41.23	96.57
0.700	940.	535.	1.76	126.4	1.0	3.786	6107.	0.93	25.64	42.24	106.72
0.700	1738.	535.	3.25	113.8	1.0	1.810	6331.	0.87	37.76	46.73	146.98
0.700	3126.	535.	5.84	106.7	1.0	0.931	6519.	0.81	56.34	44.44	198.20

ENGINE- 22 CLASS 2

ESTIMATED PERFORMANCE

MO	VO	HTO	PTO	T	CF	IS	SPC	PT2	H2	P2
				ALTITUDE - 50000. FEET						
1.86	1800.	158.3	10.6	114676.	5.25	1591.	2.26	10.00	144.3	7.21
2.00	1936.	168.5	13.2	137647.	4.92	1603.	2.25	12.25	153.6	8.84
2.10	2033.	176.1	15.5	154768.	4.69	1624.	2.22	14.16	160.6	10.22
2.20	2130.	184.2	18.1	176135.	4.50	1629.	2.21	16.37	168.0	11.82
2.50	2420.	210.6	28.9	231575.	3.86	1844.	1.95	25.20	192.3	18.21
3.00	2904.	262.1	62.2	321355.	2.90	2844.	1.27	50.31	239.7	36.41
				ALTITUDE - 60000. FEET						
2.19	2120.	183.4	11.0	105315.	4.49	1669.	2.16	10.01	167.3	7.22
2.25	2178.	188.4	12.1	115114.	4.40	1656.	2.17	10.92	171.9	7.88
2.35	2275.	197.0	14.2	127709.	4.20	1693.	2.13	12.61	179.8	9.11
2.40	2323.	201.4	15.3	137116.	4.13	1682.	2.14	13.55	183.8	9.79
2.70	2614.	230.1	24.4	188192.	3.63	1770.	2.03	20.70	210.2	14.97
3.00	2904.	262.1	38.5	247823.	3.19	1925.	1.87	31.19	239.7	22.57
				ALTITUDE - 70000. FEET						
2.53	2460.	215.0	11.7	92108.	3.81	1834.	1.96	10.17	196.4	7.35
2.60	2524.	221.4	13.0	101077.	3.73	1813.	1.99	11.17	202.2	8.07
2.70	2621.	231.4	15.2	114543.	3.60	1805.	1.99	12.84	211.4	9.29
2.80	2719.	241.7	17.7	130198.	3.48	1786.	2.02	14.75	221.0	10.67
2.90	2816.	252.5	20.6	145083.	3.36	1800.	2.00	16.91	230.9	12.23
3.00	2913.	263.6	23.9	158754.	3.22	1848.	1.95	19.35	241.1	14.01

ENGINE- 22 CLASS 2

ESTIMATED PERFORMANCE

M2	WS	WP	WSWP	WFT	PHP	PHS	V6	PT20	A0	A5	A6
ALTITUDE - 50000. FEET											
0.700	490.	300.	1.64	72.1	1.0	4.155	6001.	0.94	23.22	40.74	96.11
0.700	583.	357.	1.63	85.9	1.0	4.164	6164.	0.93	25.64	40.50	106.91
0.700	659.	396.	1.67	95.3	1.0	4.082	6264.	0.92	27.61	40.60	115.22
0.700	746.	449.	1.66	108.1	1.0	4.096	6373.	0.90	29.80	40.43	124.70
0.700	1077.	535.	2.01	125.6	1.0	3.282	6598.	0.87	37.76	41.89	153.84
0.700	1937.	535.	3.62	113.0	1.0	1.610	6818.	0.81	56.34	43.38	211.59
ALTITUDE - 60000. FEET											
0.700	457.	262.	1.74	63.1	1.0	3.902	6352.	0.91	29.57	40.24	122.07
0.700	492.	289.	1.70	69.5	1.0	3.992	6427.	0.90	30.98	39.85	128.37
0.700	556.	313.	1.78	75.4	1.0	3.832	6511.	0.89	33.51	40.11	138.14
0.700	591.	339.	1.75	81.5	1.0	3.894	6569.	0.88	34.87	39.84	144.09
0.700	848.	442.	1.92	106.3	1.0	3.544	6820.	0.85	44.33	40.21	180.42
0.700	1201.	535.	2.25	128.8	1.0	3.029	7041.	0.81	56.34	40.86	223.23
ALTITUDE - 70000. FEET											
0.700	430.	209.	2.06	50.2	1.0	3.297	6646.	0.87	38.79	40.66	155.50
0.700	466.	232.	2.01	55.7	1.0	3.381	6720.	0.86	40.91	40.17	164.32
0.700	525.	264.	1.99	63.5	1.0	3.418	6819.	0.85	44.33	39.76	178.02
0.700	590.	303.	1.95	72.9	1.0	3.489	6918.	0.84	48.04	39.32	193.27
0.700	663.	335.	1.98	80.6	1.0	3.436	7002.	0.82	52.03	39.22	208.62
0.700	743.	357.	2.08	85.9	1.0	3.265	7074.	0.81	56.34	39.39	223.88

[redacted]

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

ENGINE 22

SUPPLEMENTARY DATA

MO	WS	WHX	WT	AO	AHX	AOT
		ALTITUDE	0. FEET			
0.50	938.	520.	1458.	21.99	12.19	34.18
0.75	1115.	520.	1635.	17.41	8.12	25.53
1.00	1348.	520.	1868.	15.77	6.08	21.85
		ALTITUDE -	10000. FEET			
0.60	714.	433.	1147.	19.50	11.82	31.32
0.90	910.	520.	1430.	16.56	9.46	26.02
1.20	1231.	520.	1751.	16.79	7.09	23.88
1.40	1468.	520.	1988.	17.14	6.07	23.21
1.60	1816.	520.	2336.	18.52	5.30	23.82
		ALTITUDE -	20000. FEET			
0.77	562.	335.	897.	17.24	10.28	27.52
1.00	693.	419.	1112.	16.41	9.92	26.33
1.20	852.	520.	1372.	16.78	10.24	27.02
1.50	1191.	520.	1711.	18.75	8.19	26.94
1.80	1646.	520.	2166.	21.55	6.81	28.36
		ALTITUDE -	30000. FEET			
1.17	553.	327.	880.	16.65	9.85	26.50
1.30	640.	392.	1032.	17.27	10.58	27.85
1.40	716.	440.	1156.	17.93	11.02	28.95
1.50	802.	520.	1322.	18.75	12.16	30.91
1.90	1297.	520.	1817.	23.88	9.57	33.45
2.40	2345.	520.	2865.	34.04	7.55	41.59
		ALTITUDE -	36000. FEET			
1.39	548.	322.	870.	17.84	10.48	28.32
1.50	622.	385.	1007.	18.75	11.61	30.36
1.60	700.	426.	1126.	19.75	12.02	31.77
1.70	789.	478.	1267.	20.94	12.69	33.63
2.00	1138.	520.	1658.	25.64	11.72	37.36
2.40	1842.	520.	2362.	34.49	9.74	44.23
2.80	3004.	520.	3524.	48.03	8.31	56.34

[redacted]

ENGINE 22 CONT'D.

SUPPLEMENTARY DATA

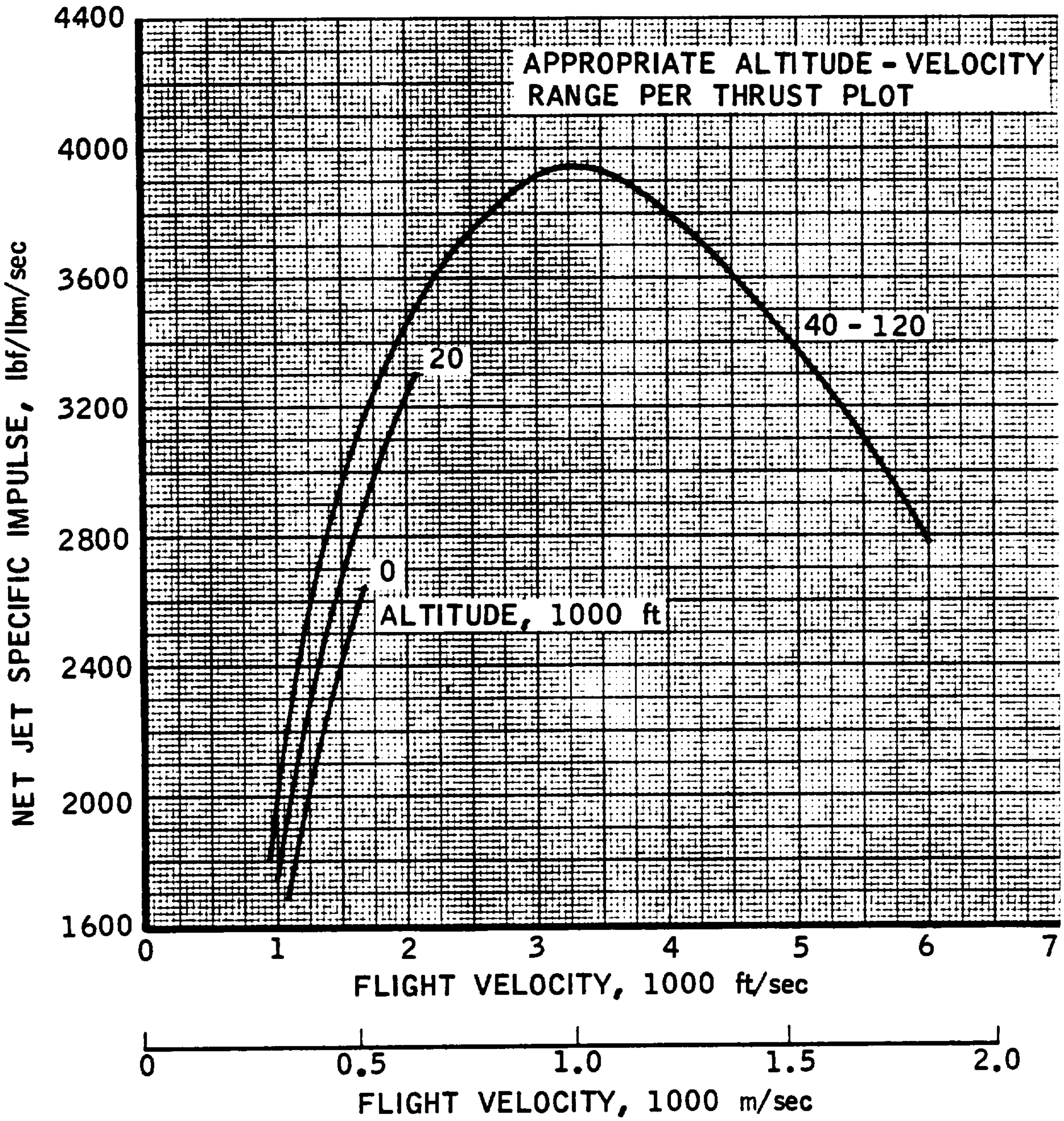
MO	WS	WHX	WT	AO	AHX	AOT
			ALTITUDE - 40000. FEET			
1.52	525.	317.	842.	18.92	11.42	30.34
1.65	614.	373.	987.	20.32	12.34	32.66
1.85	782.	478.	1260.	23.08	14.11	37.19
2.00	940.	520.	1460.	25.64	14.18	39.82
2.50	1738.	520.	2258.	37.76	11.30	49.06
3.00	3126.	520.	3646.	56.34	9.37	65.71
			ALTITUDE - 50000. FEET			
1.86	490.	292.	782.	23.22	13.84	37.06
2.00	583.	347.	930.	25.64	15.26	40.90
2.10	659.	385.	1044.	27.61	16.13	43.74
2.20	746.	436.	1182.	29.80	17.42	47.22
2.50	1077.	520.	1597.	37.76	18.23	55.99
3.00	1937.	520.	2457.	56.34	15.12	71.46
			ALTITUDE - 60000. FEET			
2.19	457.	255.	712.	29.57	16.50	46.07
2.25	492.	281.	773.	30.98	17.69	48.67
2.35	556.	304.	860.	33.51	18.32	51.83
2.40	591.	329.	920.	34.87	19.41	54.28
2.70	848.	429.	1277.	44.33	22.43	66.76
3.00	1201.	520.	1721.	56.34	24.39	80.73
			ALTITUDE - 70000. FEET			
2.53	430.	203.	633.	38.79	18.31	57.10
2.60	466.	225.	691.	40.91	19.75	60.66
2.70	525.	256.	781.	44.33	21.62	65.95
2.80	590.	294.	884.	48.04	23.94	71.98
2.90	663.	326.	989.	52.03	28.58	77.61
3.00	743.	347.	1090.	56.34	26.31	82.65

Eng. No. 22

RAMJET SPECIFIC IMPULSE

SUBSONIC COMBUSTION

NO PRESSURE FIELD

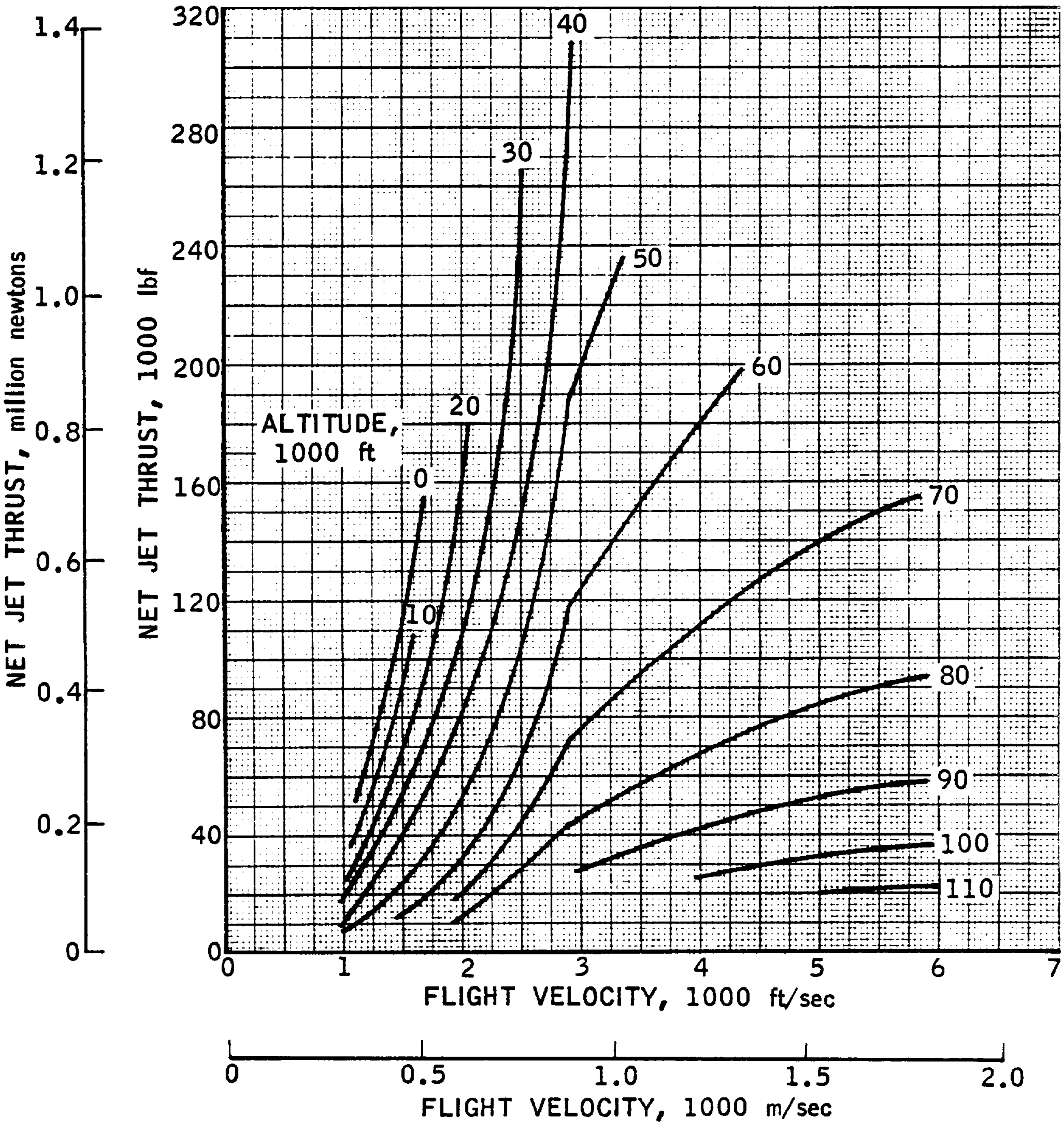


Eng. No. 22

RAMJET THRUST

SUBSONIC COMBUSTION

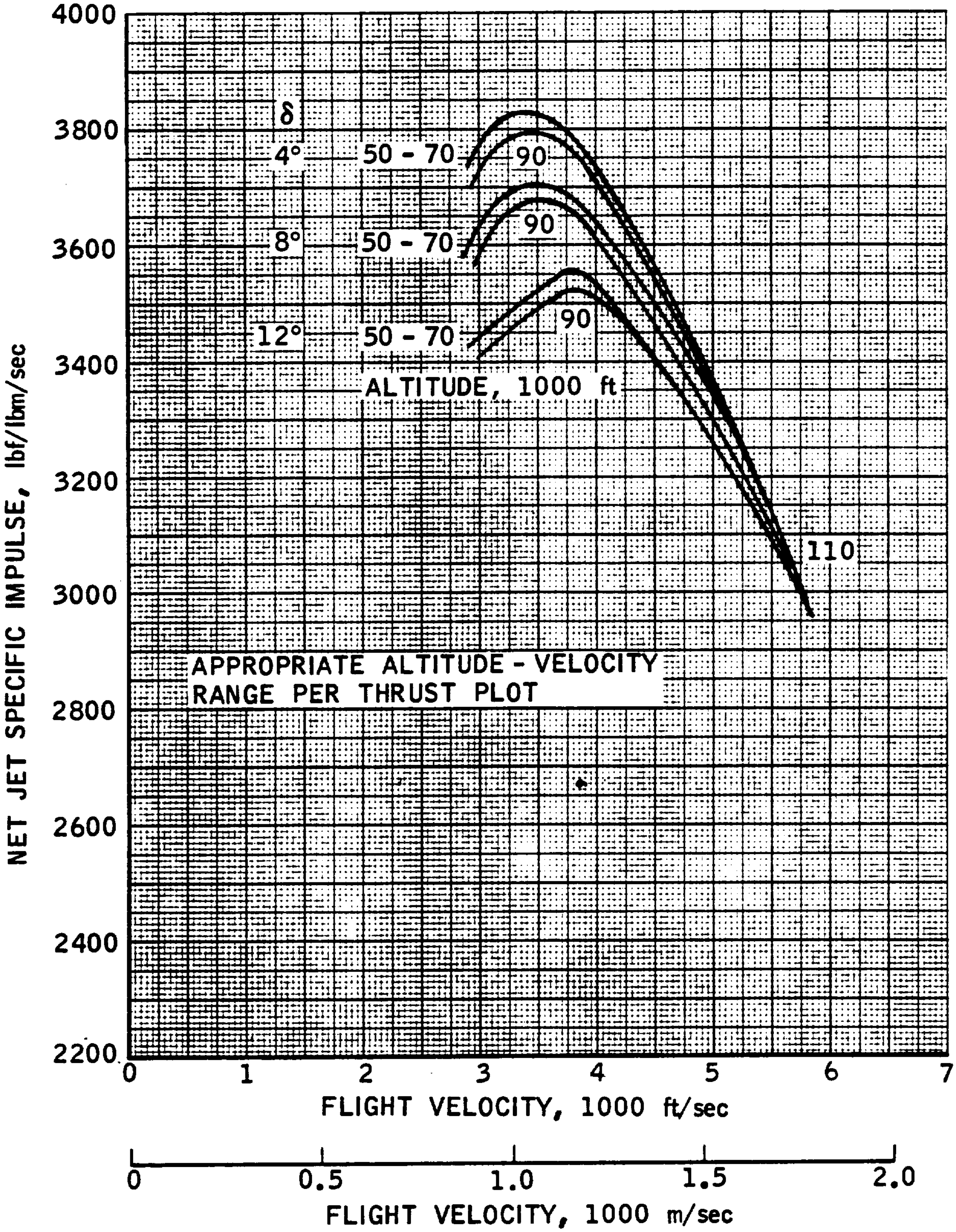
NO PRESSURE FIELD



[redacted]

Eng. No. 22

RAMJET SPECIFIC IMPULSE
SUBSONIC COMBUSTION
EFFECT OF PRESSURE FIELD



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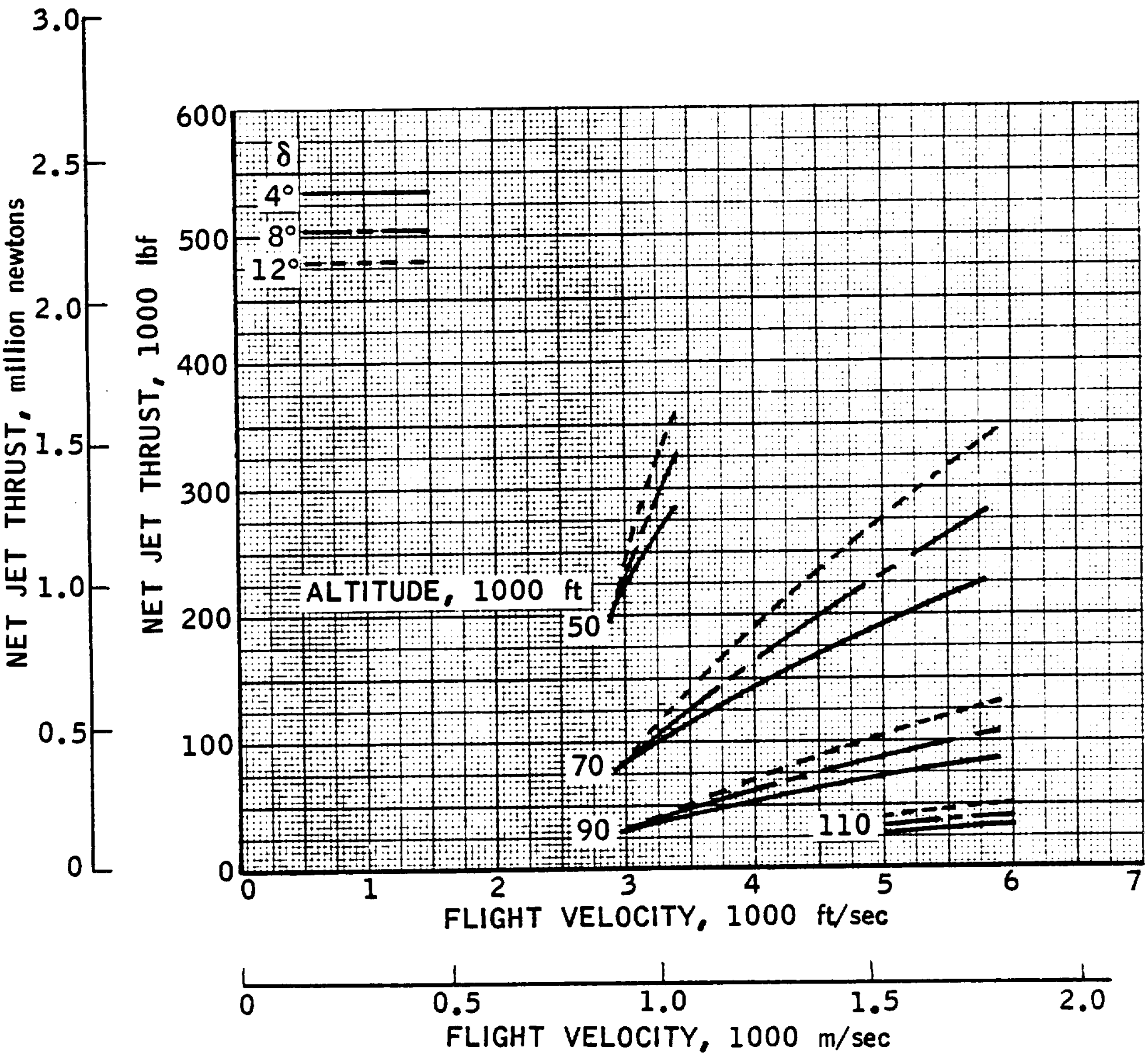
RAMJET THRUST

SUBSONIC COMBUSTION

EFFECT OF PRESSURE FIELD

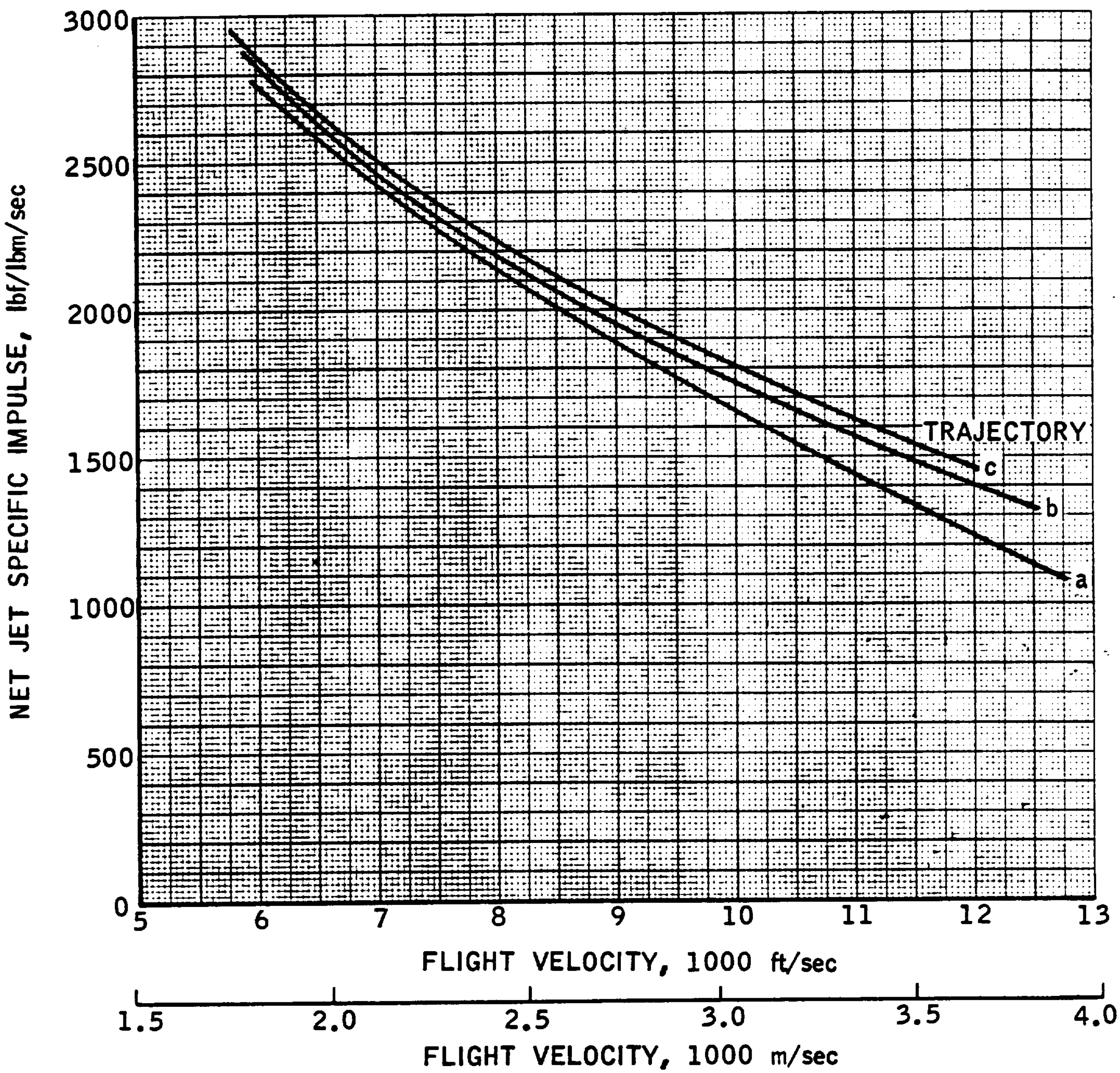


Eng. No. 22

RAMJET SPECIFIC IMPULSE

SUPERSONIC COMBUSTION

NO PRESSURE FIELD

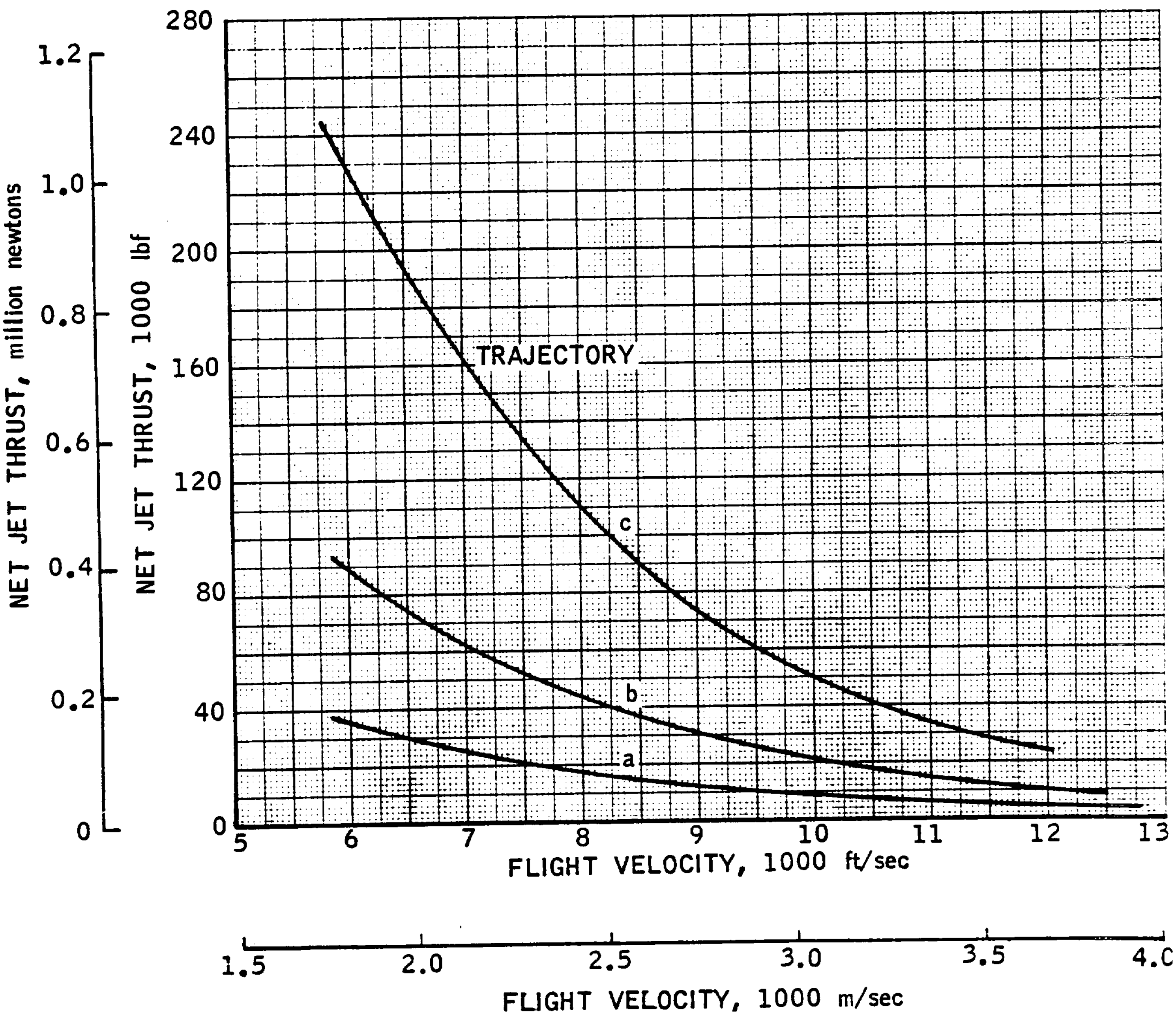


[redacted]

RAMJET THRUST

SUPERSONIC COMBUSTION

NO PRESSURE FIELD



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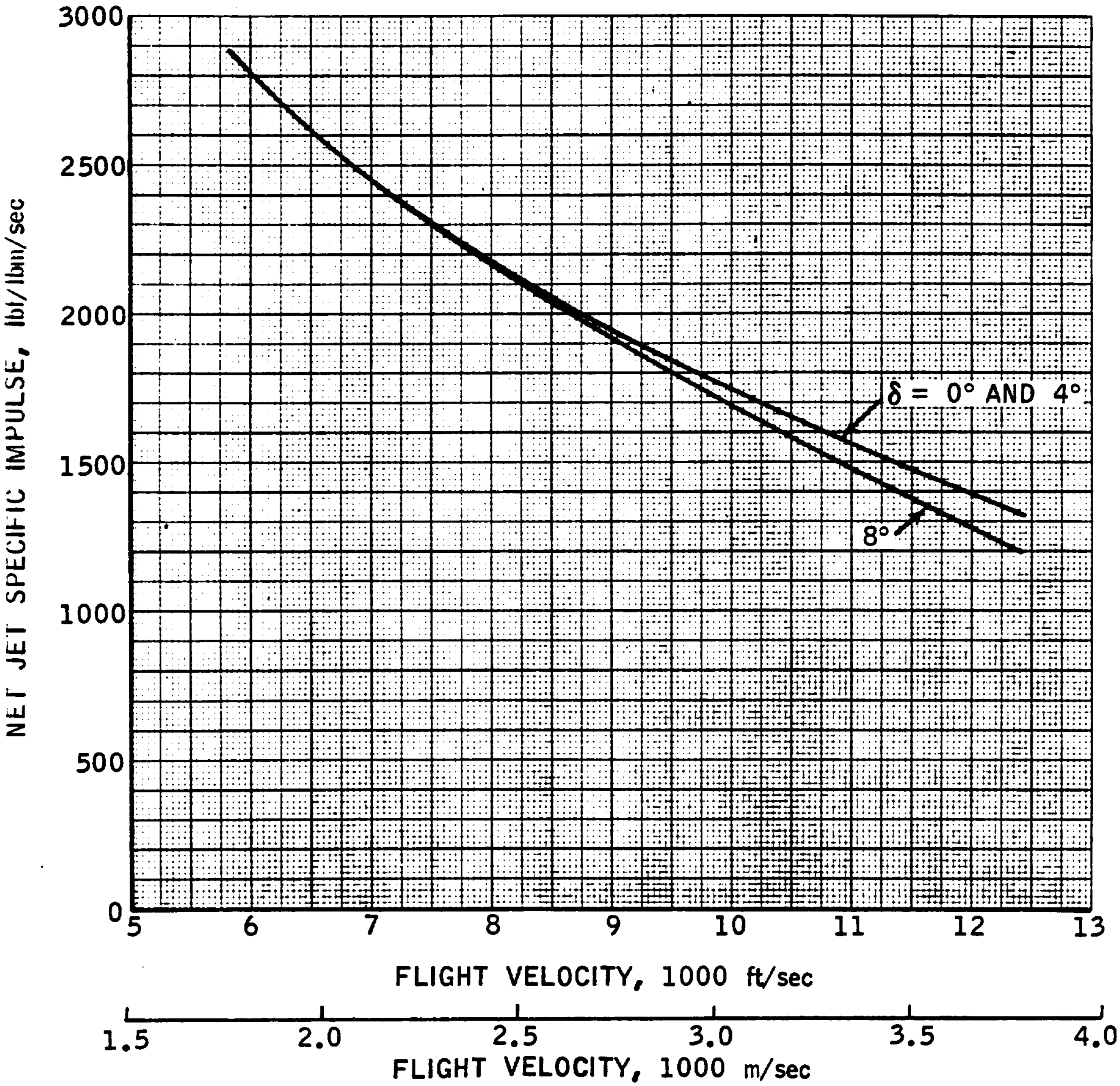
Eng. No. 22

RAMJET SPECIFIC IMPULSE

SUPERSONIC COMBUSTION

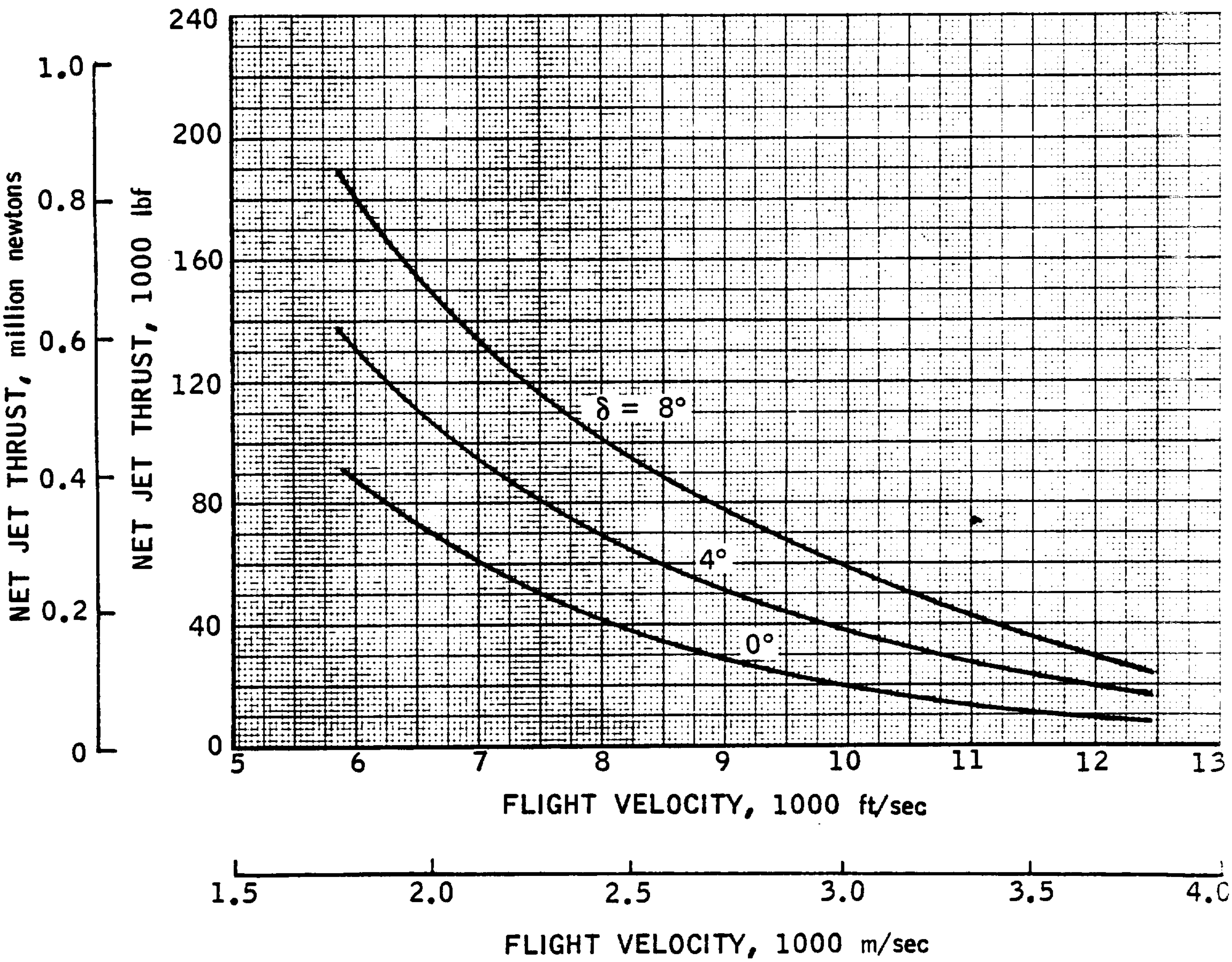
EFFECT OF PRESSURE FIELD

TRAJECTORY b



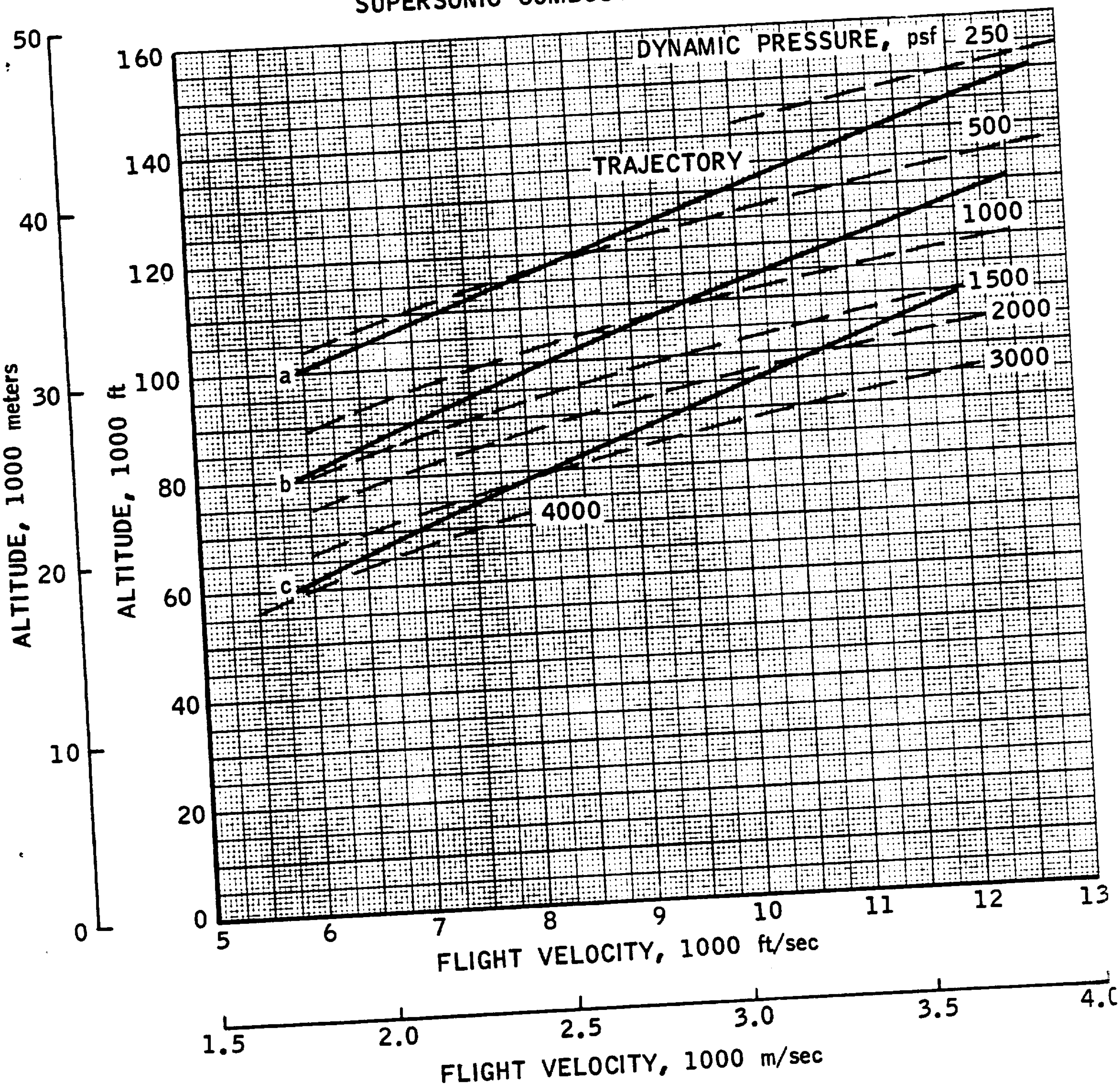
[redacted]

RAMJET THRUST
SUPERSONIC COMBUSTION
EFFECT OF PRESSURE FIELD
TRAJECTORY b



REFERENCE TRAJECTORIES

SUPERSONIC COMBUSTION RAMJET



SUMMARY: SENSITIVITY ANALYSIS - BASES

The performance data shown in the present report, as well as in the Class 0 and 1 engine documentation (References 1 and 2), was computed on the basis of a singular set of internal component efficiencies, as well as stated operating points (e.g., design mass flow ratio, W_s/W_p). Component sensitivity studies were conducted as a major effort within the Class 2 study phase. The bases for the analysis are given here, followed immediately by the results.

The approach used was to define baseline performance, specific impulse and thrust (both net jet), for a reference trajectory. This was accomplished for each of the engine's operating modes over the normal range of flight velocities for that mode. It is appropriate here, to comment to the point that sensitivity studies of trajectory effects, per se, are already intrinsic in the previously displayed performance maps.

Proceeding from this basis of specific impulse and thrust discrete trends, each of the important engine variables was perturbed from the baseline value, e.g., afterburner combustion efficiency: Baseline value - 0.95, sensitivity excursions - 0.90 and 1.00. All of the remaining variables were essentially held at the baseline, or nominal value. Any exception to this resulted from the engine performance computer program's automatic compensation characteristics which, in some instances "retunes" some of the engine internal variables. The extent and implications of this situation are covered in the main technical report (Reference 3).

This section presents the following bases for the sensitivity analysis results to be given subsequently:

1. Reference trajectories

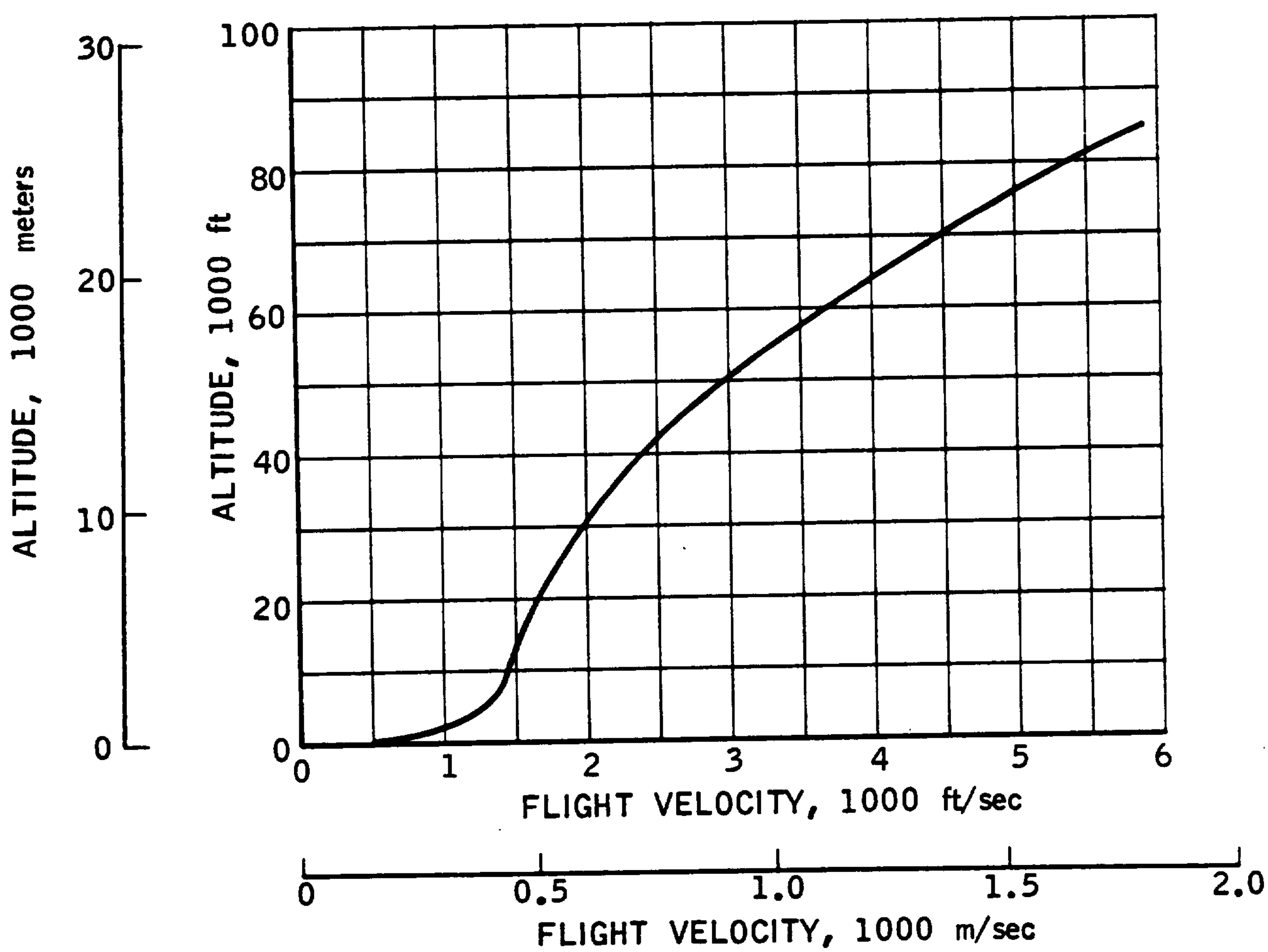
2. Baseline specific impulse (on reference trajectory)

3. Baseline thrust (on reference trajectory)

4. Ranges of sensitivity variables, with reference to the baseline values (both curve and tabular presentation)

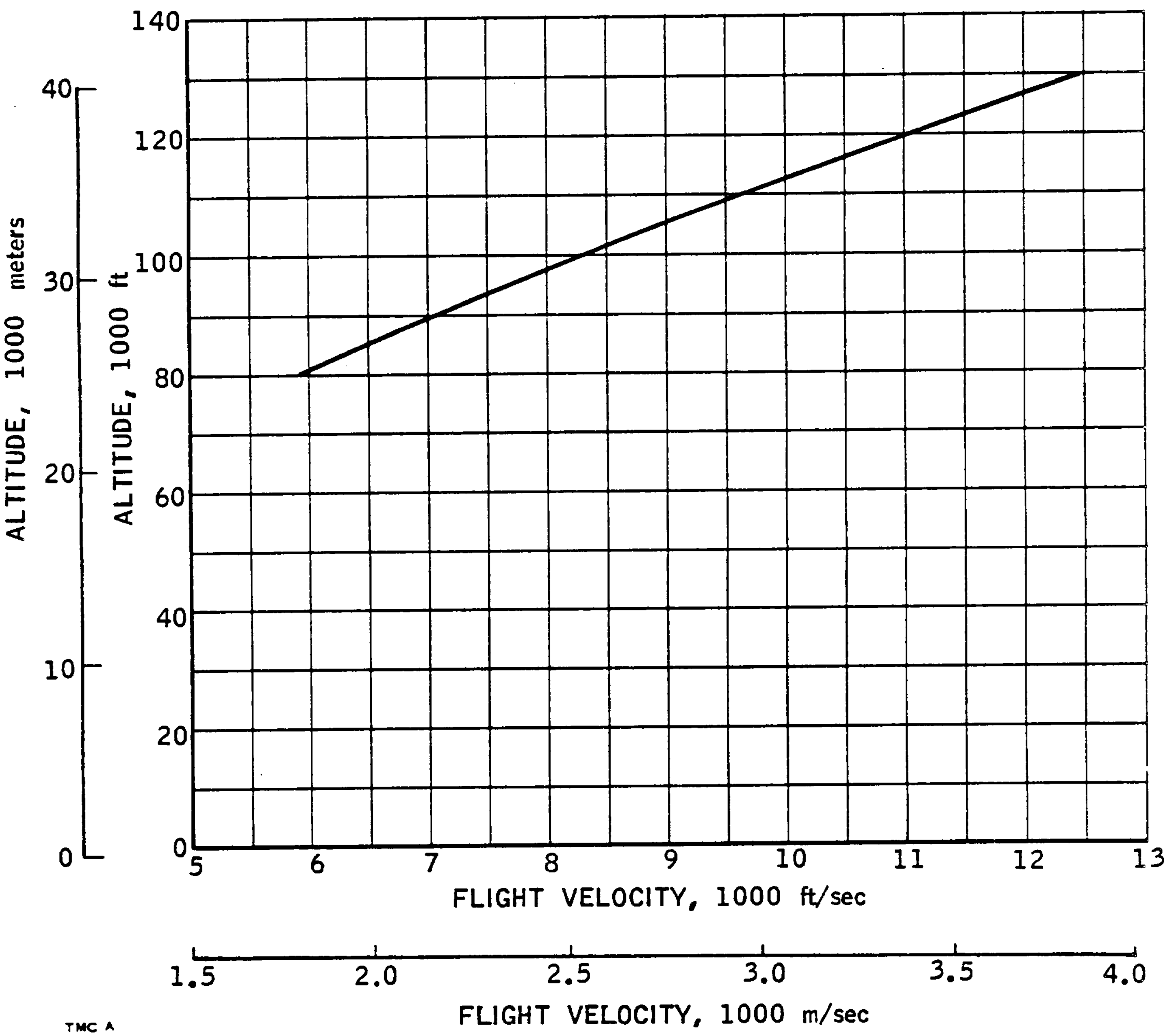
REFERENCE TRAJECTORY SENSITIVITY ANALYSIS

SUBSONIC COMBUSTION MODES



REFERENCE TRAJECTORY SENSITIVITY ANALYSIS

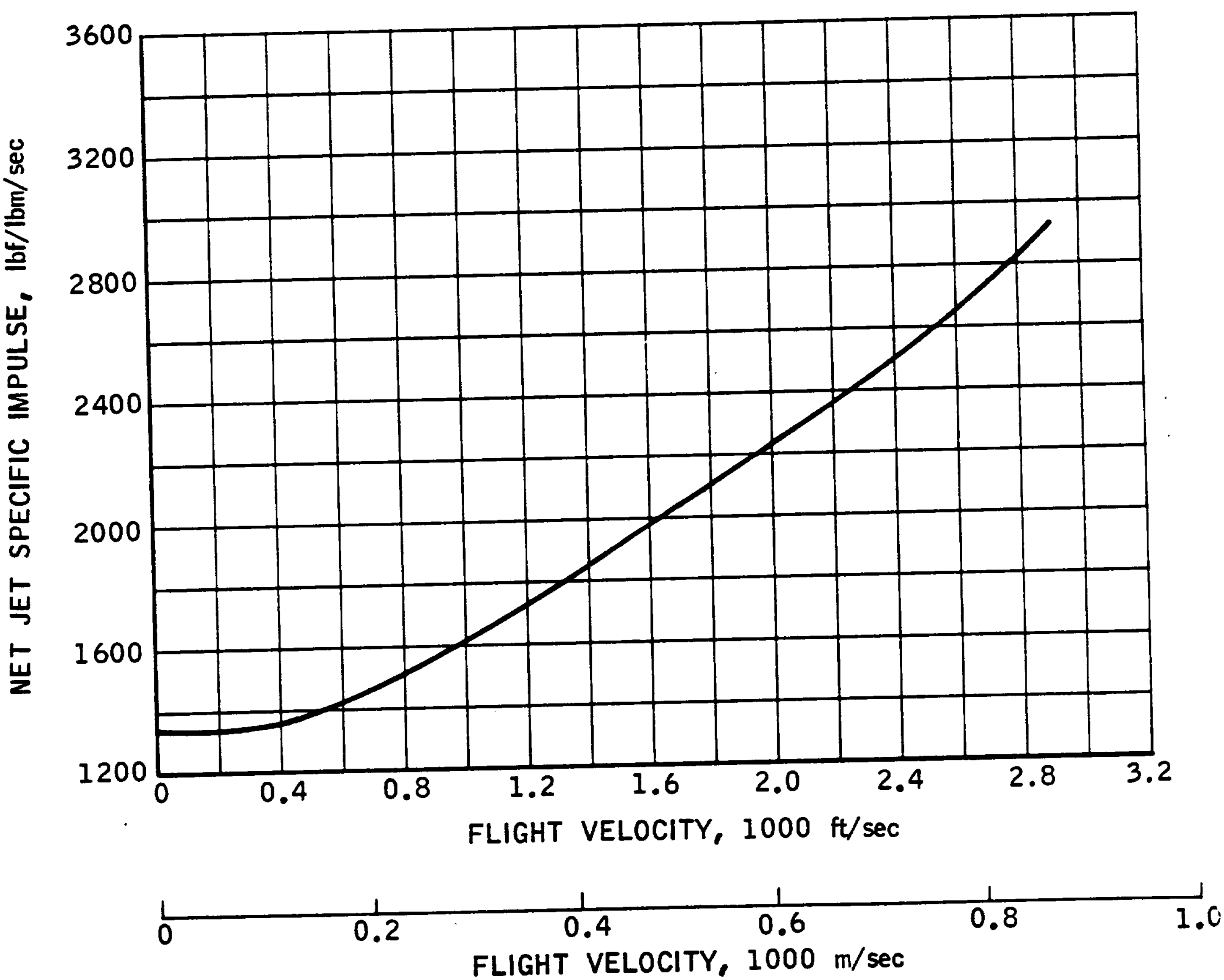
SUPERSONIC COMBUSTION RAMJET



TMC A

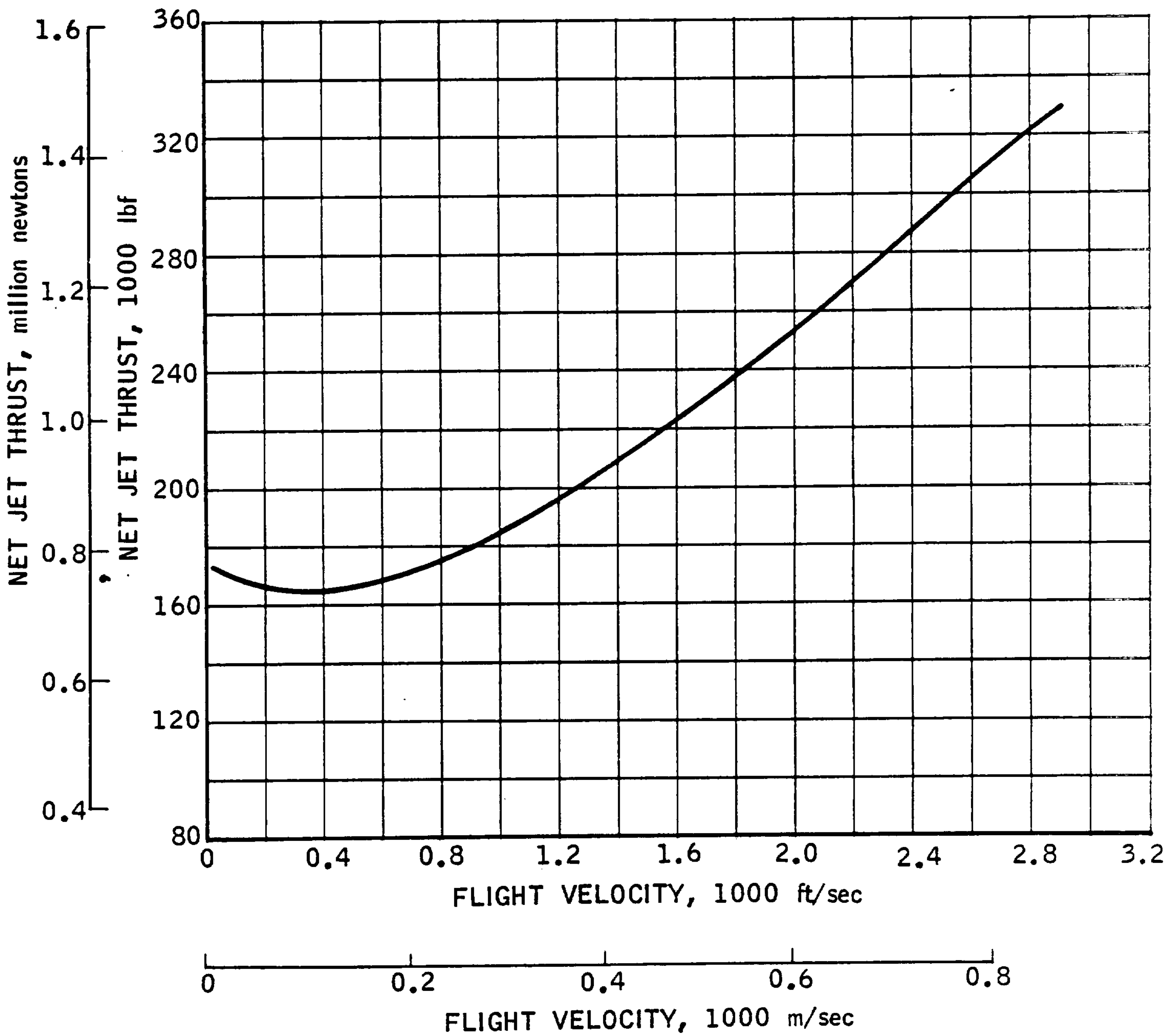
[redacted]

BASELINE SPECIFIC IMPULSE
EJECTOR MODE



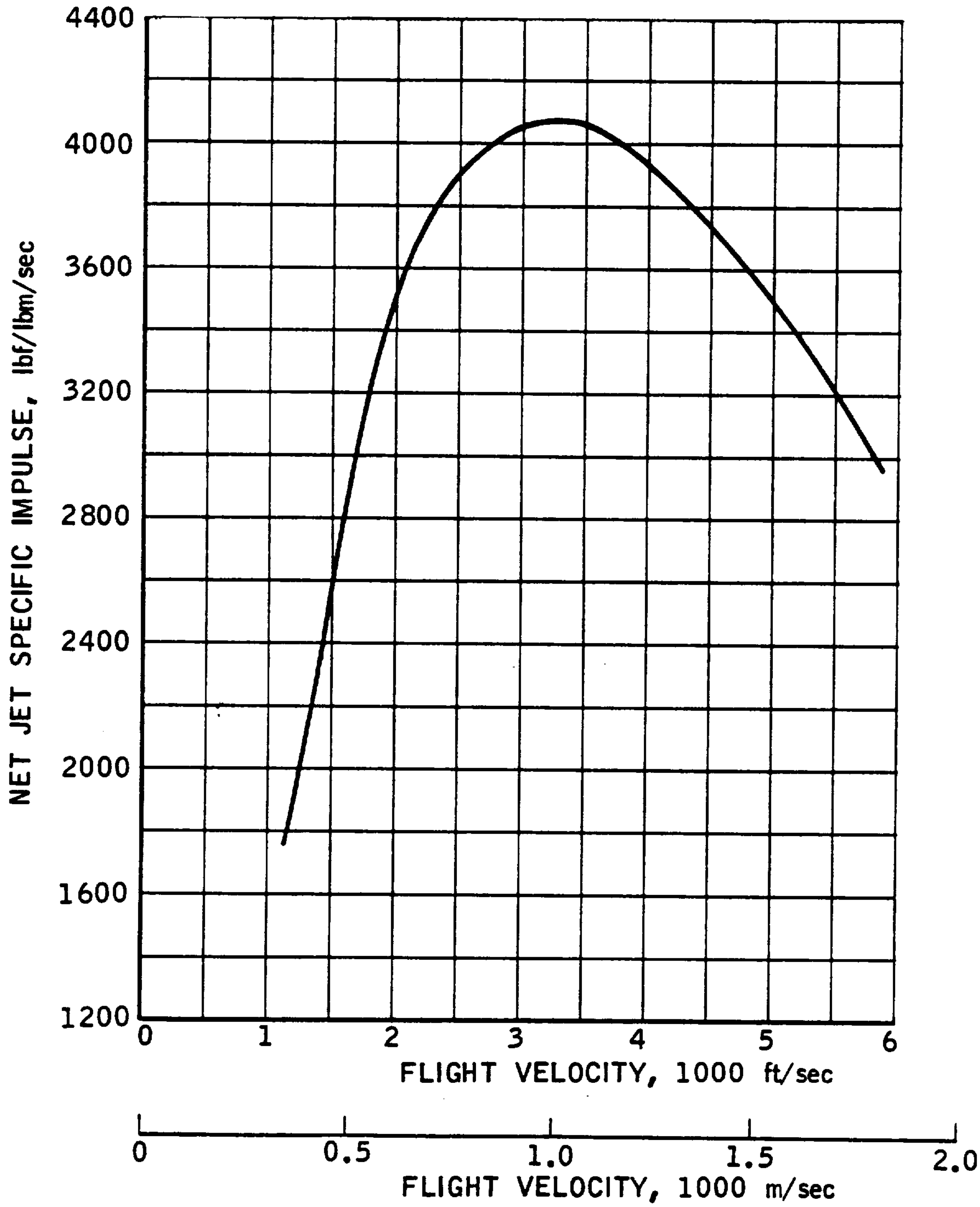
Eng. No. 22

BASELINE THRUST
EJECTOR MODE



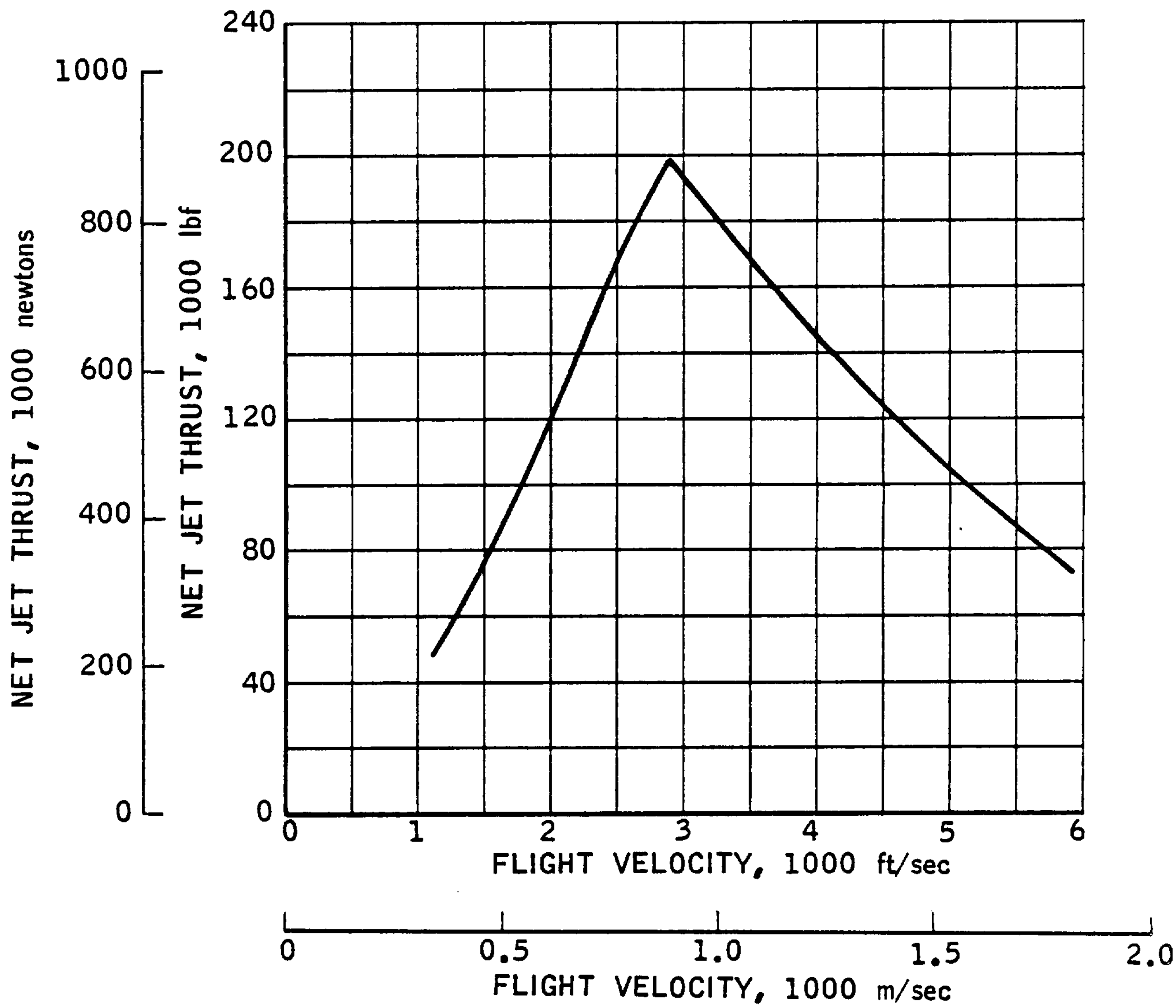
Eng. No. 22

BASELINE SPECIFIC IMPULSE
SUBSONIC COMBUSTION RAMJET



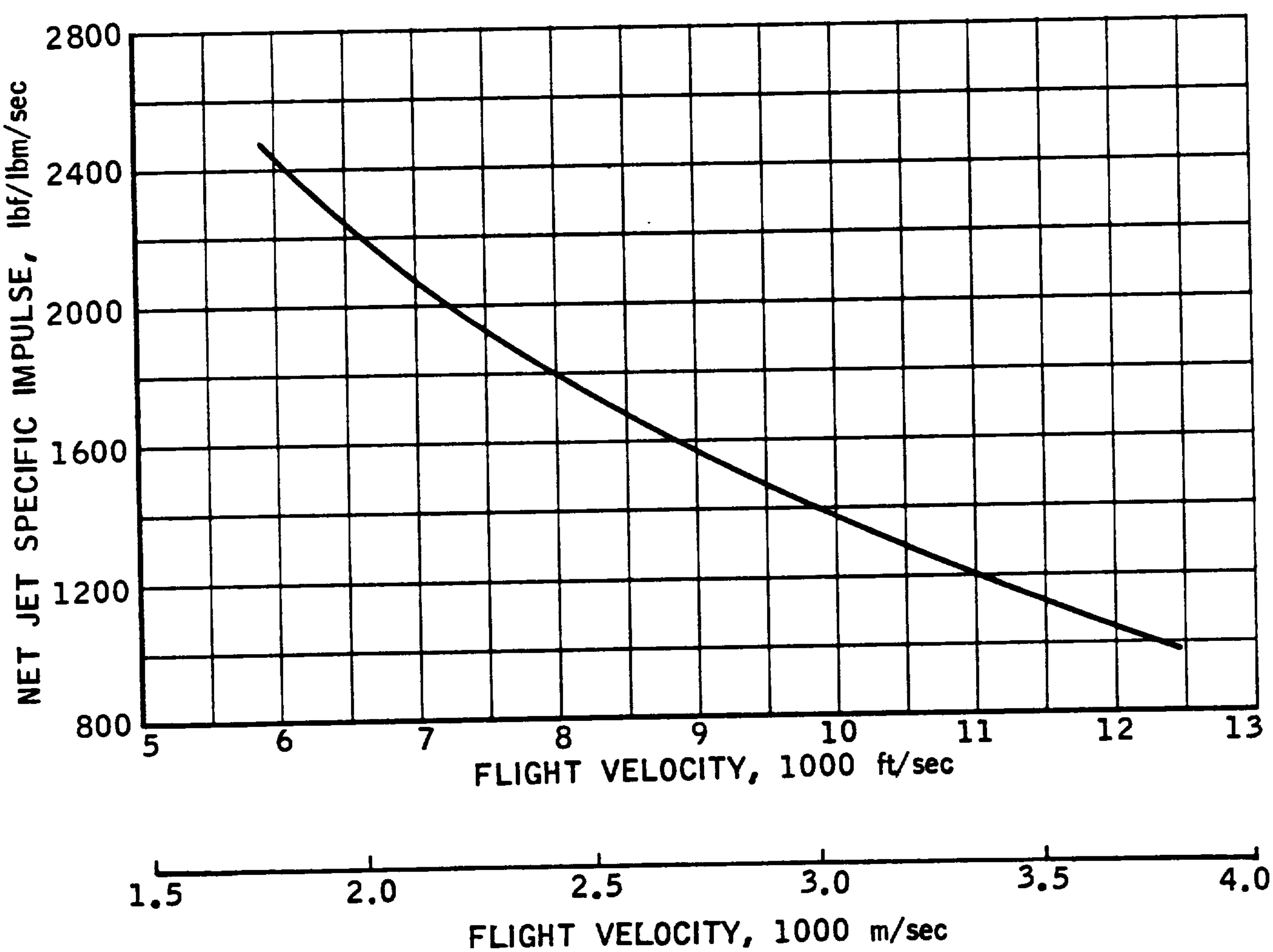
[redacted]

BASELINE THRUST
SUBSONIC COMBUSTION RAMJET

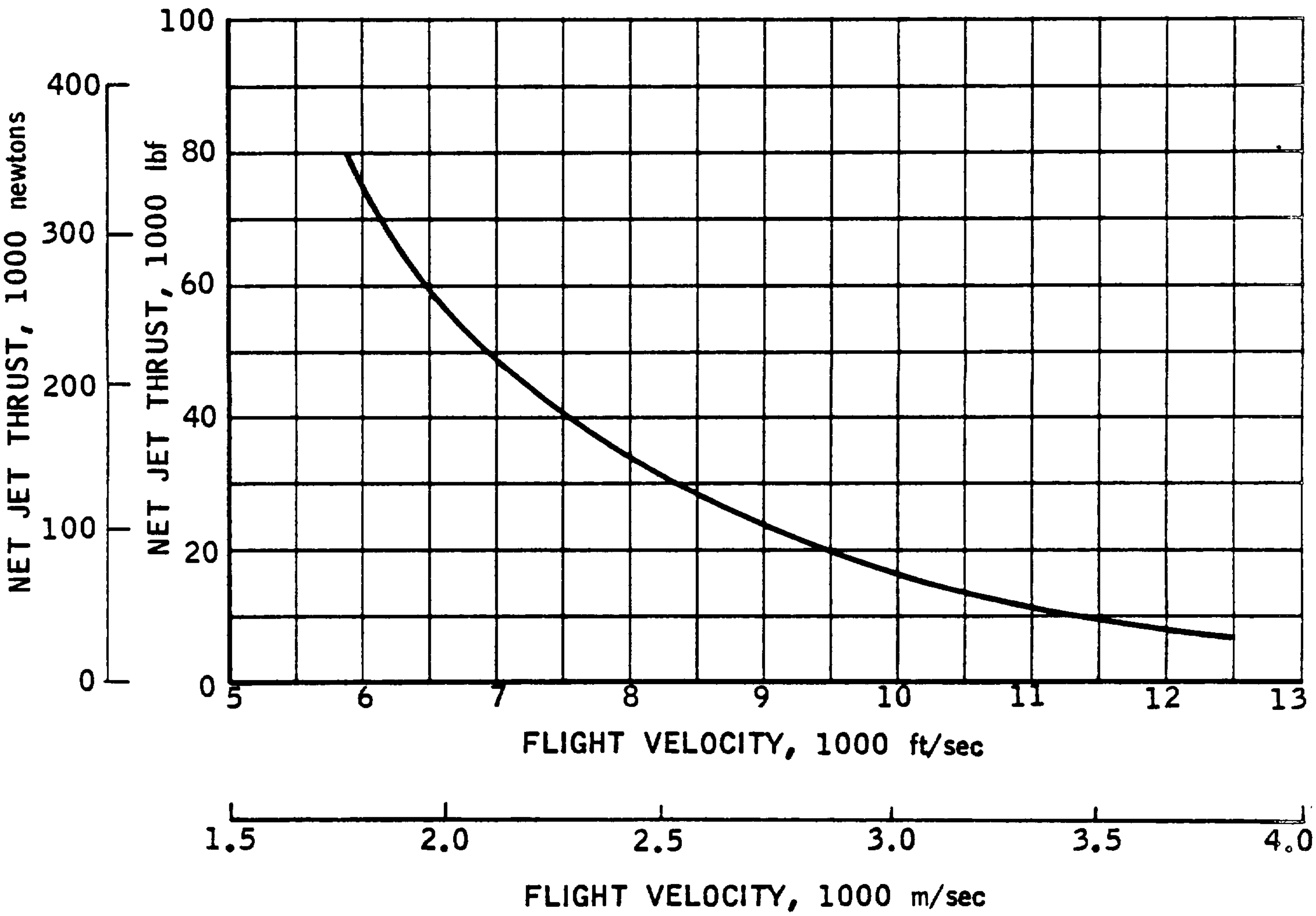


[redacted]

BASELINE SPECIFIC IMPULSE
SUPERSONIC COMBUSTION RAMJET



BASELINE THRUST
SUPERSONIC COMBUSTION RAMJET



SENSITIVITY ANALYSIS RANGES

	Base-line	Range	
Ejector Mode:			
Inlet - Pressure recovery, P_{t_2}/P_{t_0}	Figure E		
Heat Exchanger			
Equivalence ratio, ϕ_{HX}	Figure F		
Equivalence ratio, ϕ_{HX}	Figure G		
Primary			
Equivalence ratio, ϕ	1.00	1.10	0.90
Combustion efficiency, η_{c*}	0.975	1.00	0.92
Nozzle efficiency, η_N	0.98	1.00	0.95
Mixer - Mixing efficiency, η_M	0.80	1.00	0.50
Afterburner			
Equivalence ratio, ϕ_{AB}	Figure H		
Equivalence ratio, ϕ_{AB}	Figure I		
Combustion efficiency, η_c	0.95	1.00	0.85
Exit			
Nozzle efficiency, η_N	0.98	1.00	0.95
Exit area ratio, A_6/A_5	Figure J		
Subsonic Combustion Ramjet:			
Inlet - Pressure recovery, P_{t_2}/P_{t_0}	Figure E		
Combustor			
Equivalence ratio, ϕ	1.00	1.50	0.50
Combustion efficiency, η_c	0.95	1.00	0.85
Exit			
Nozzle efficiency, η_N	0.98	1.00	0.95
Exit area ratio, A_6/A_5	Figure K		
Supersonic Combustion Ramjet:			
Inlet - Pressure recovery, P_{t_2}/P_{t_0}	Figure L		
Combustor			
Equivalence ratio, ϕ	1.00	0.75	0.50
Combustion efficiency, η_c	0.95	0.90	0.85
Exit			
Nozzle efficiency, η_N	0.98	1.00	0.96
Exit/Capture area ratio, A_6/A_c	1.50	4.00	1.00

Figure E INLET PRESSURE RECOVERY SENSITIVITY ANALYSIS

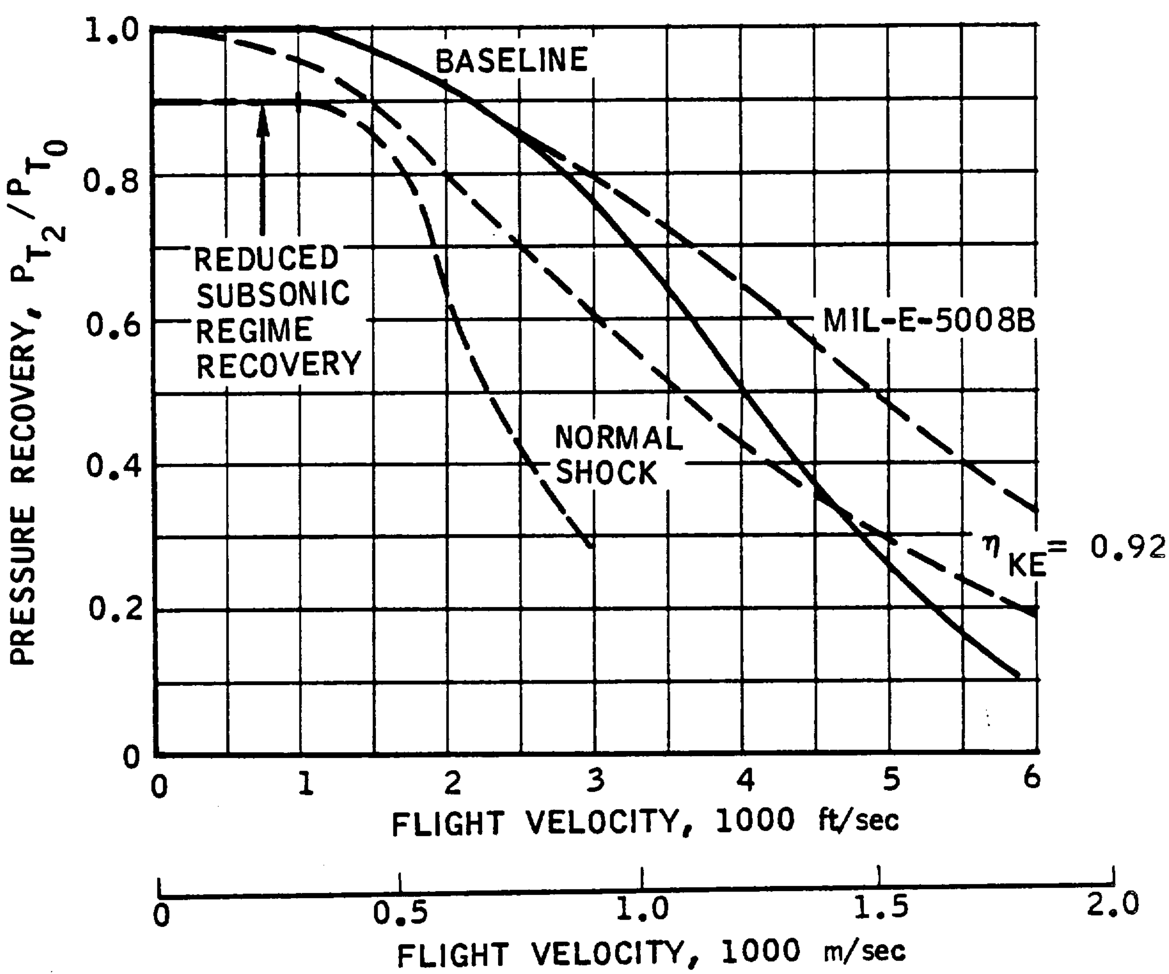


Figure F HEAT EXCHANGER EQUIVALENCE RATIO SENSITIVITY ANALYSIS RANGE

EJECTOR MODE

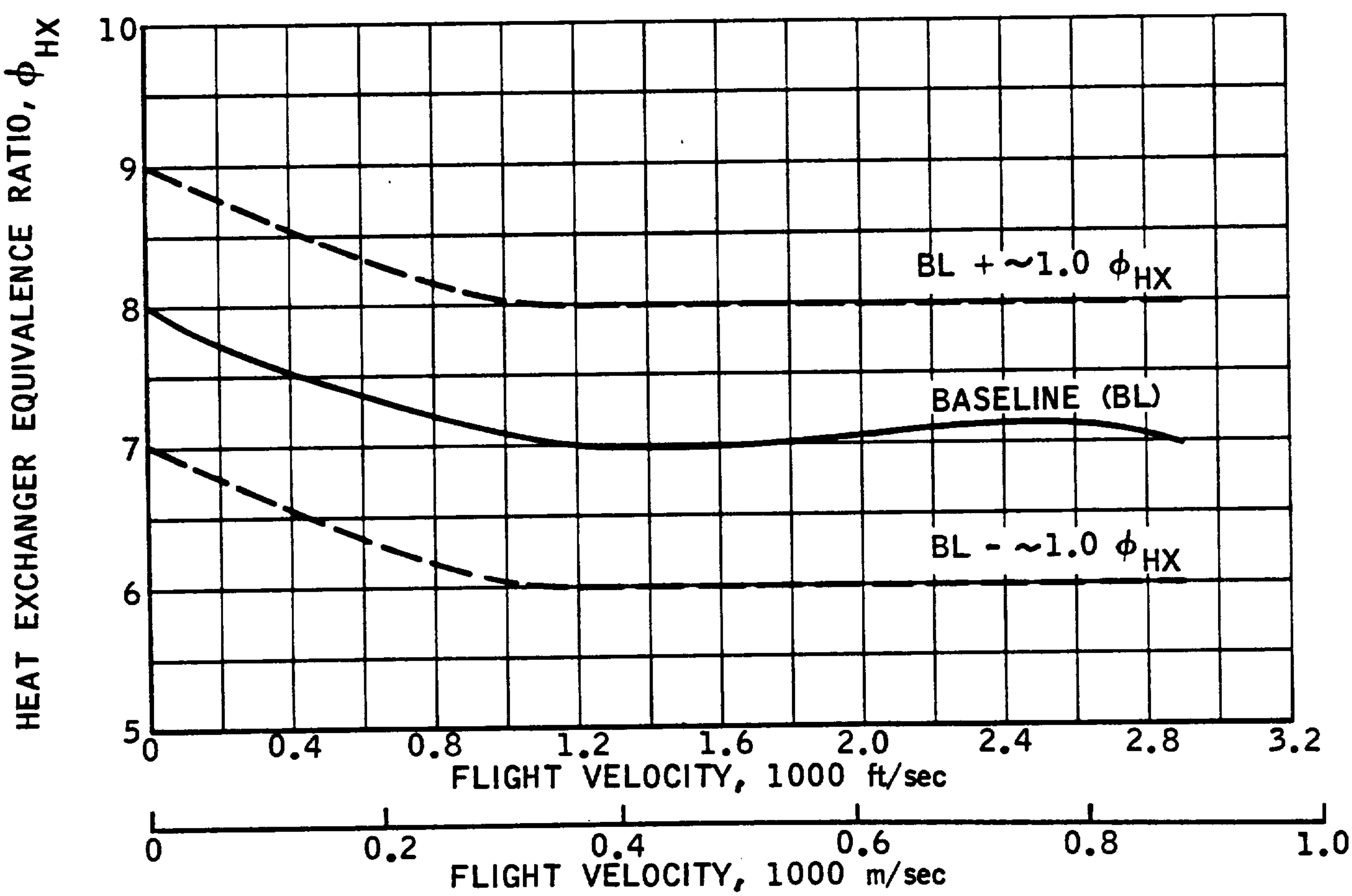


Figure G HEAT EXCHANGER EQUIVALENCE RATIO SENSITIVITY ANALYSIS RANGE

EJECTOR MODE

EFFECT OF INLET PRESSURE RECOVERY ON ϕ_{HX} FOR CONSTANT LIQUEFIED AIRFLOW

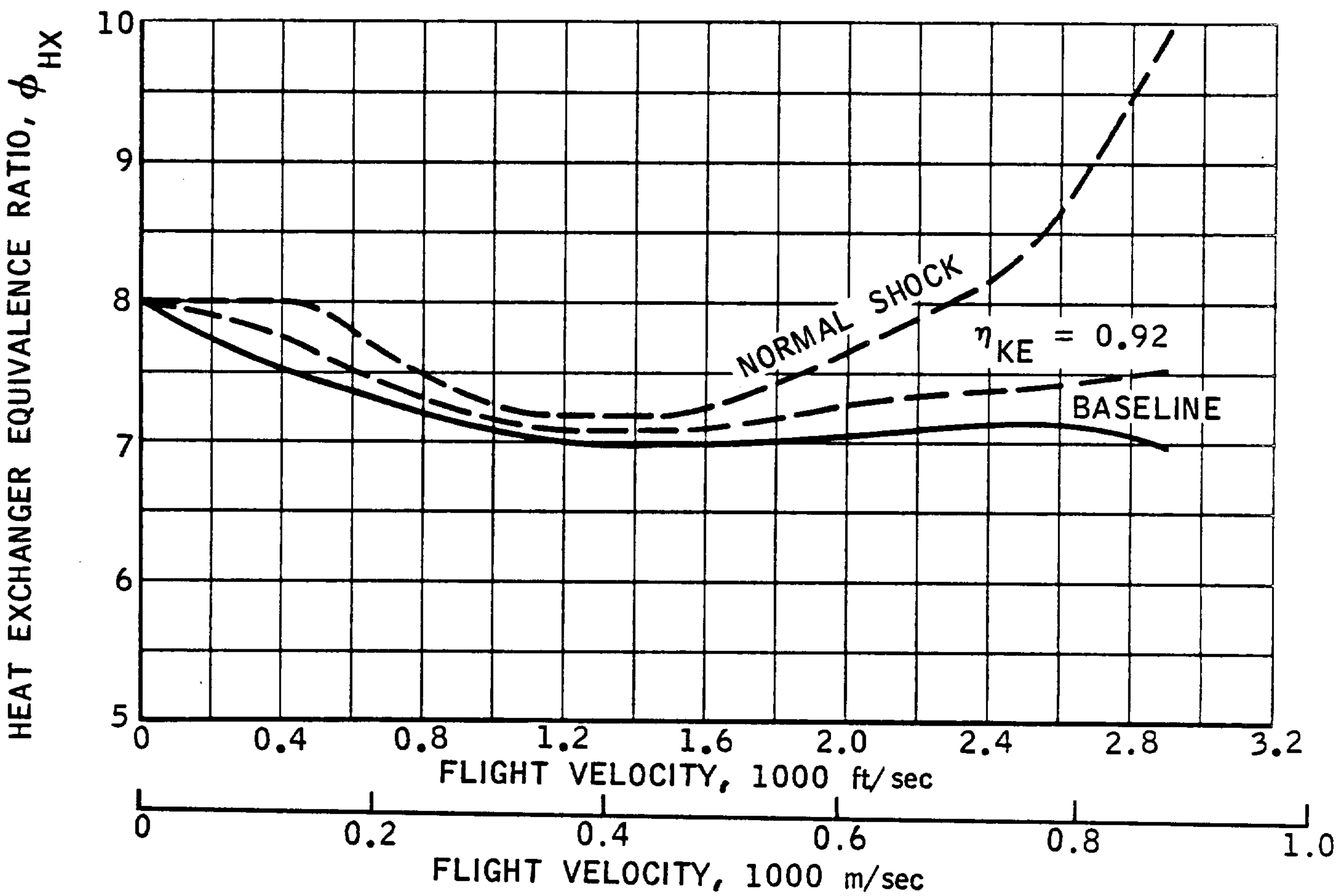


Figure H AFTERBURNER EQUIVALENCE RATIO SENSITIVITY ANALYSIS RANGE

EJECTOR MODE

BASELINE INLET PRESSURE RECOVERY

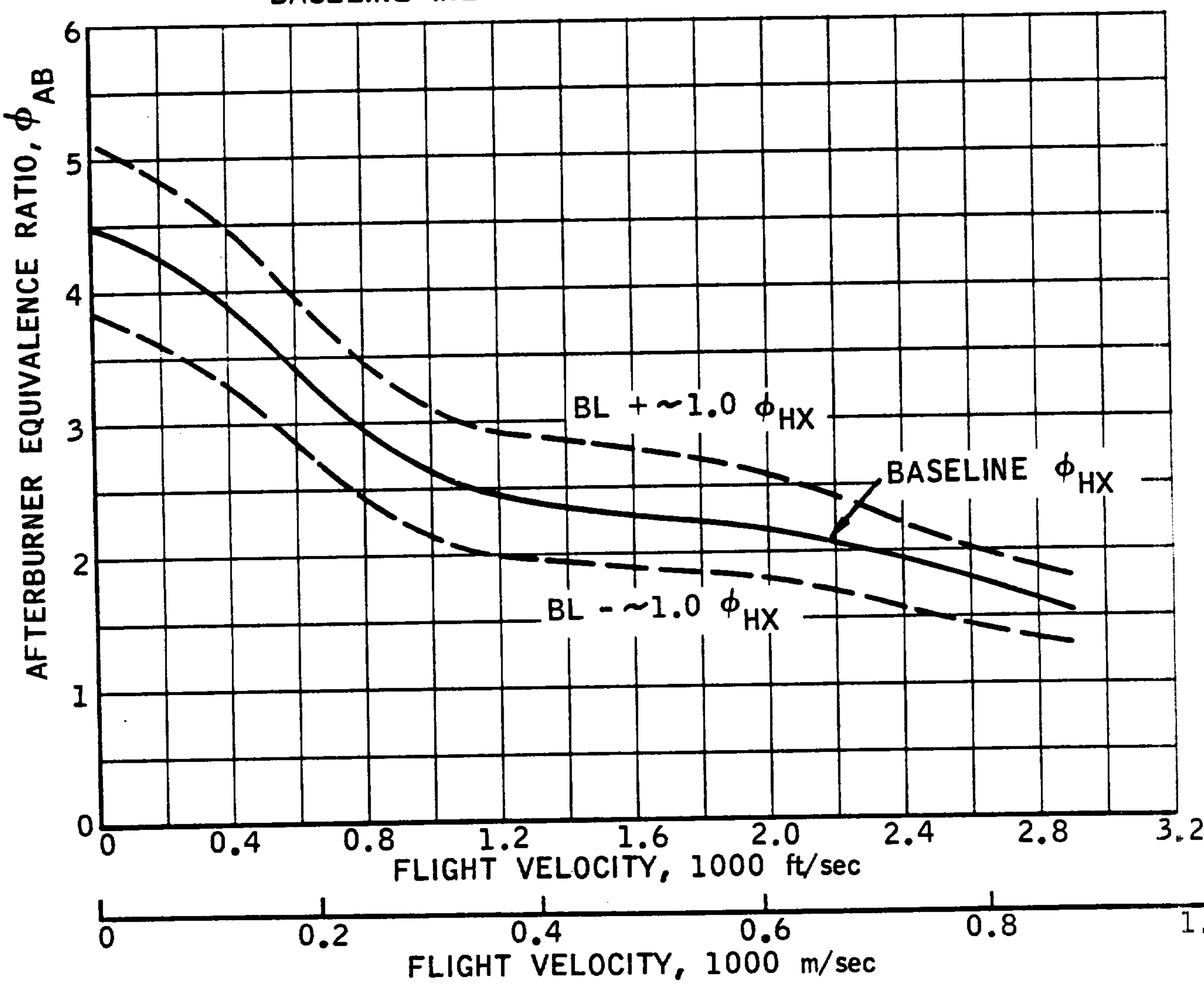


Figure 1 AFTERBURNER EQUIVALENCE RATIO SENSITIVITY ANALYSIS RANGE

EJECTOR MODE

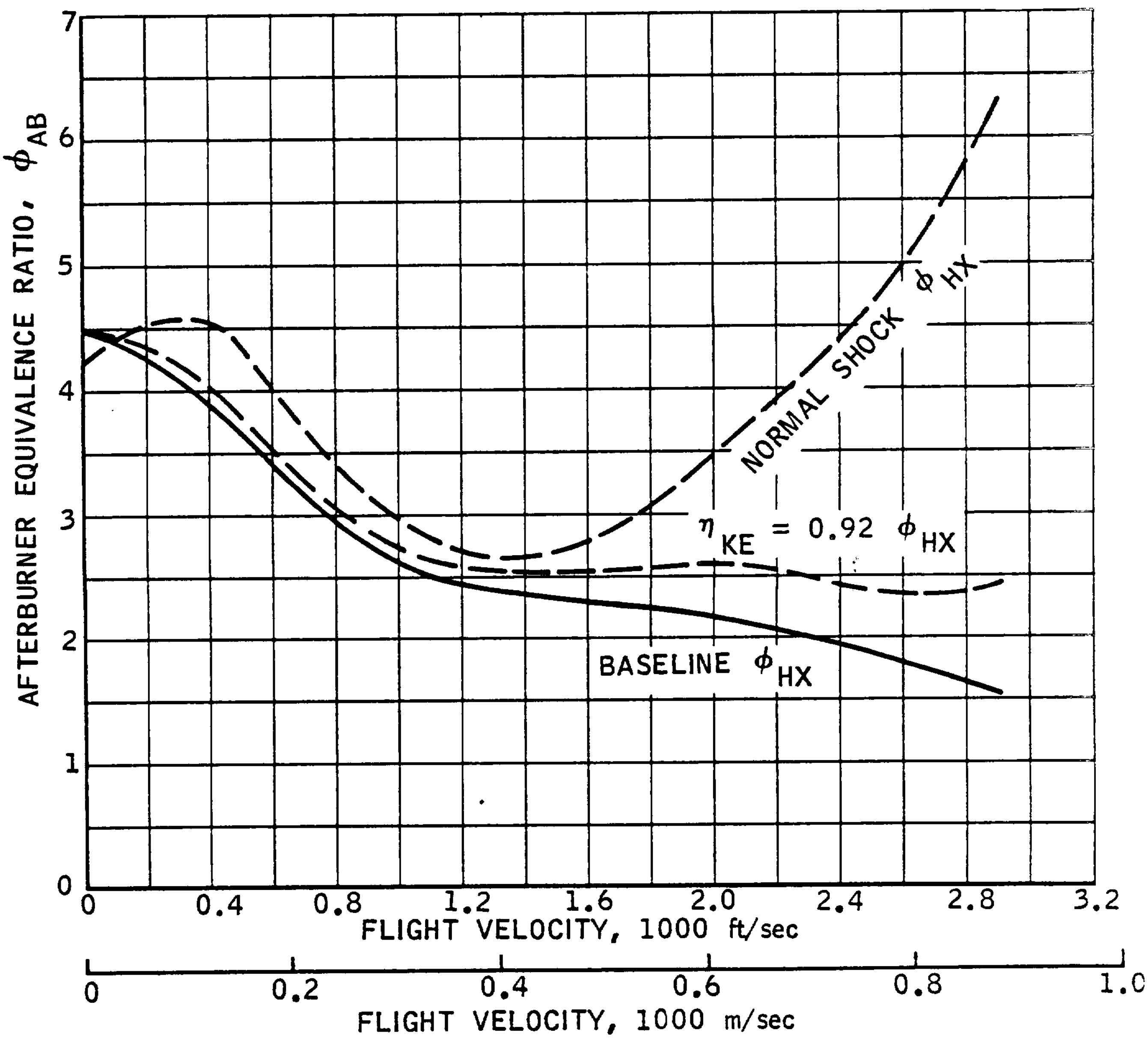
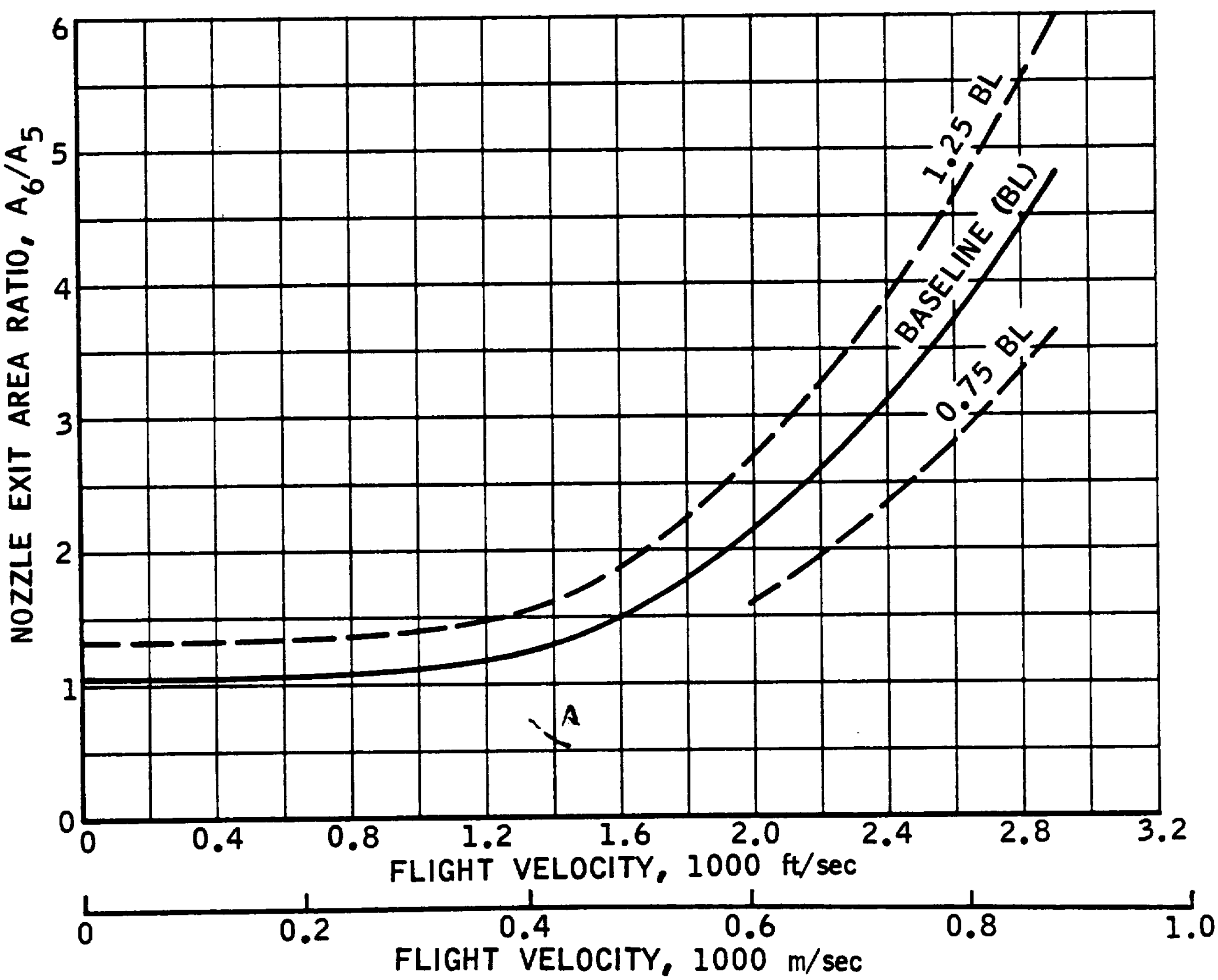


Figure J

EXIT NOZZLE AREA RATIO
SENSITIVITY ANALYSIS RANGE

EJECTOR MODE



[redacted]

Figure K

EXIT NOZZLE AREA RATIO SENSITIVITY ANALYSIS RANGE

SUBSONIC COMBUSTION RAMJET

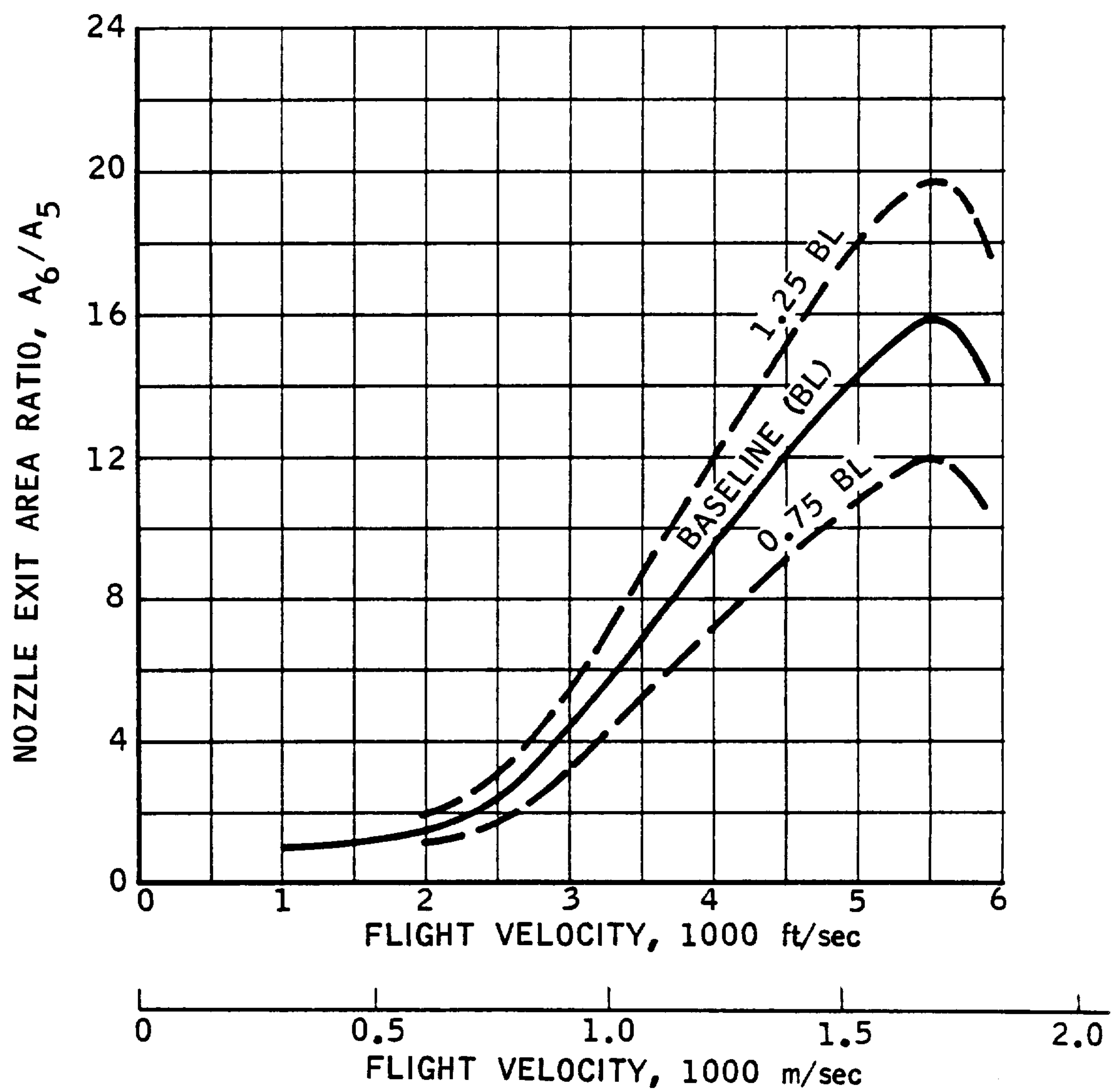
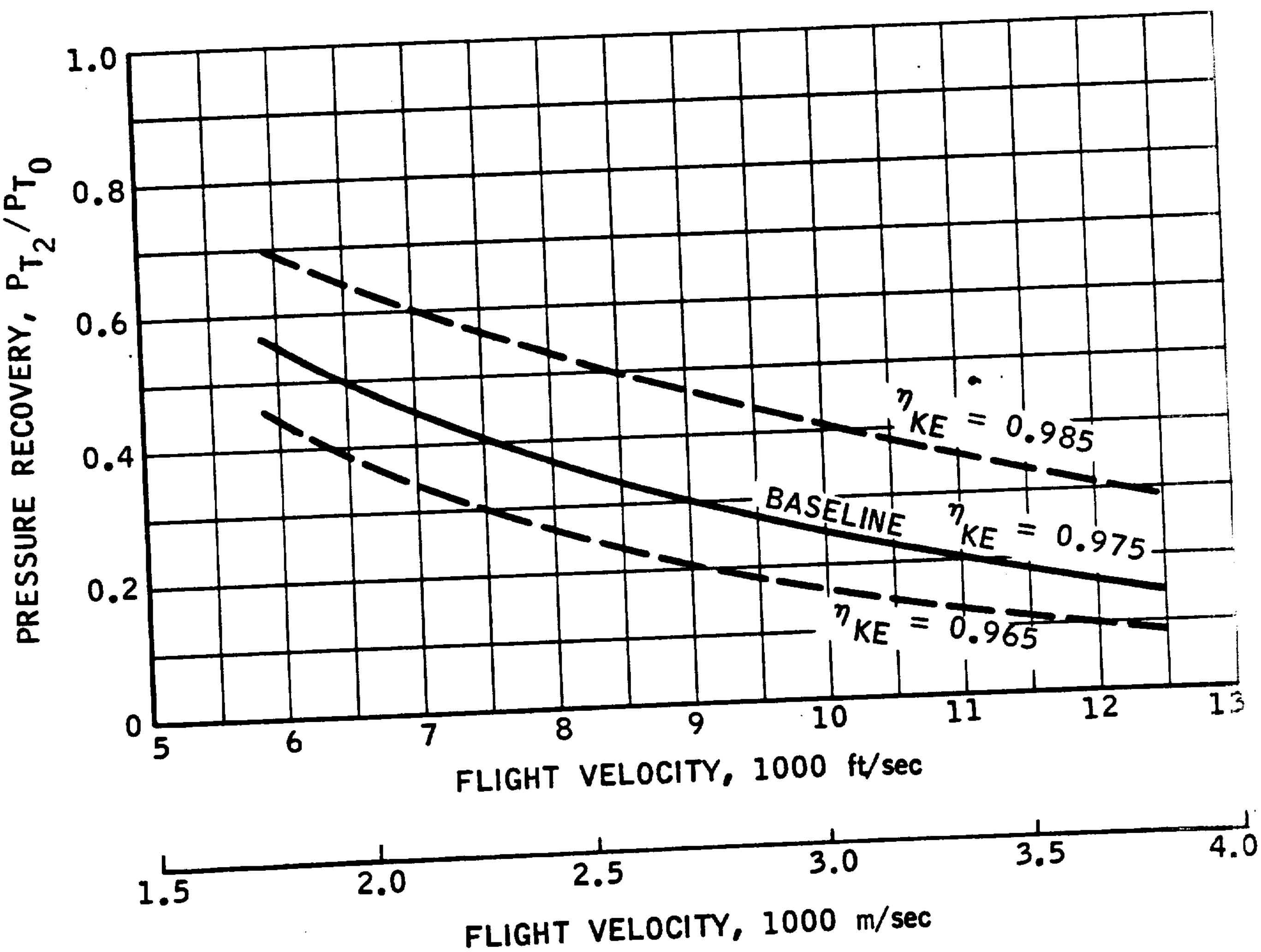


Figure L INLET PRESSURE RECOVERY SENSITIVITY ANALYSIS RANGE

SUPERSONIC COMBUSTION RAMJET



SENSITIVITY ANALYSIS - RESULTS

For the reference conditions stated in the previous section, resulting specific impulse and thrust perturbations are presented here. Performance is normalized to the baseline trends given over the appropriate flight velocity ranges.

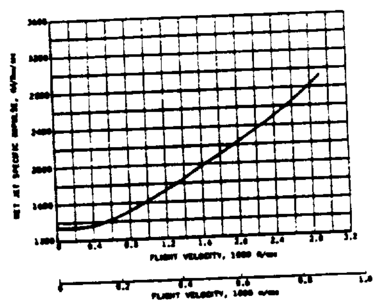
The specific impulse and thrust data are both displayed on individual sheets for each sensitivity variable. On the same sheet, a miniature plot of the absolute specific impulse and thrust baseline characteristic is shown for nominal reference purposes. For precise readings, the full-sized curve appearing previously (its page number is indicated) should be referred to.

The section concludes with a plot reflecting subsystem weight variations on uninstalled engine thrust/weight ratio.

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

INLET PRESSURE RECOVERY EFFECT
EJECTOR MODE

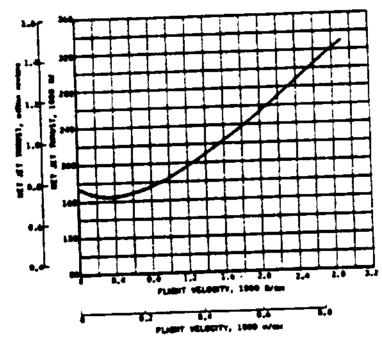
Page 145
Eng. No. 22
BASELINE SPECIFIC IMPULSE EJECTOR MODE

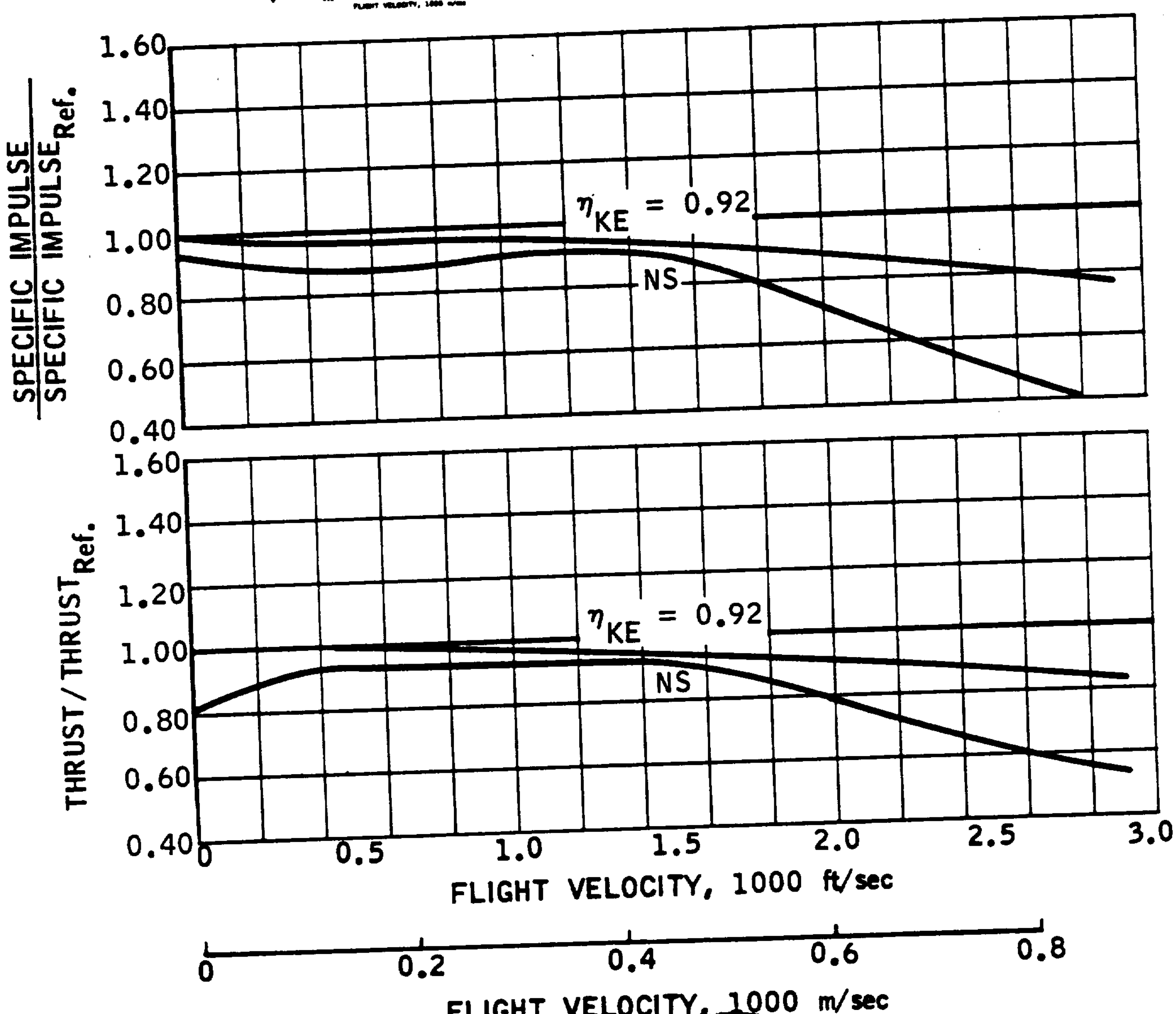


Eng. No. 22

Baseline
P_{T_2} / P_{T_0}:
Figure E
(Page 152)

Page 146
Eng. No. 22
BASELINE THRUST EJECTOR MODE





PRIMARY ROCKET EQUIVALENCE RATIO EFFECT
EJECTOR MODE

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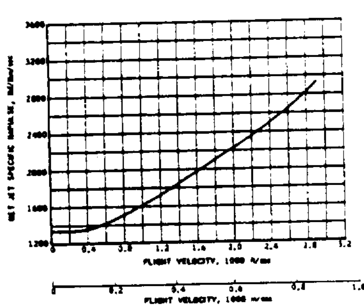

Eng. No. 22

Baseline

$\phi = 1.00$

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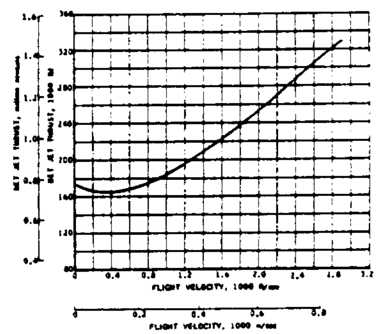

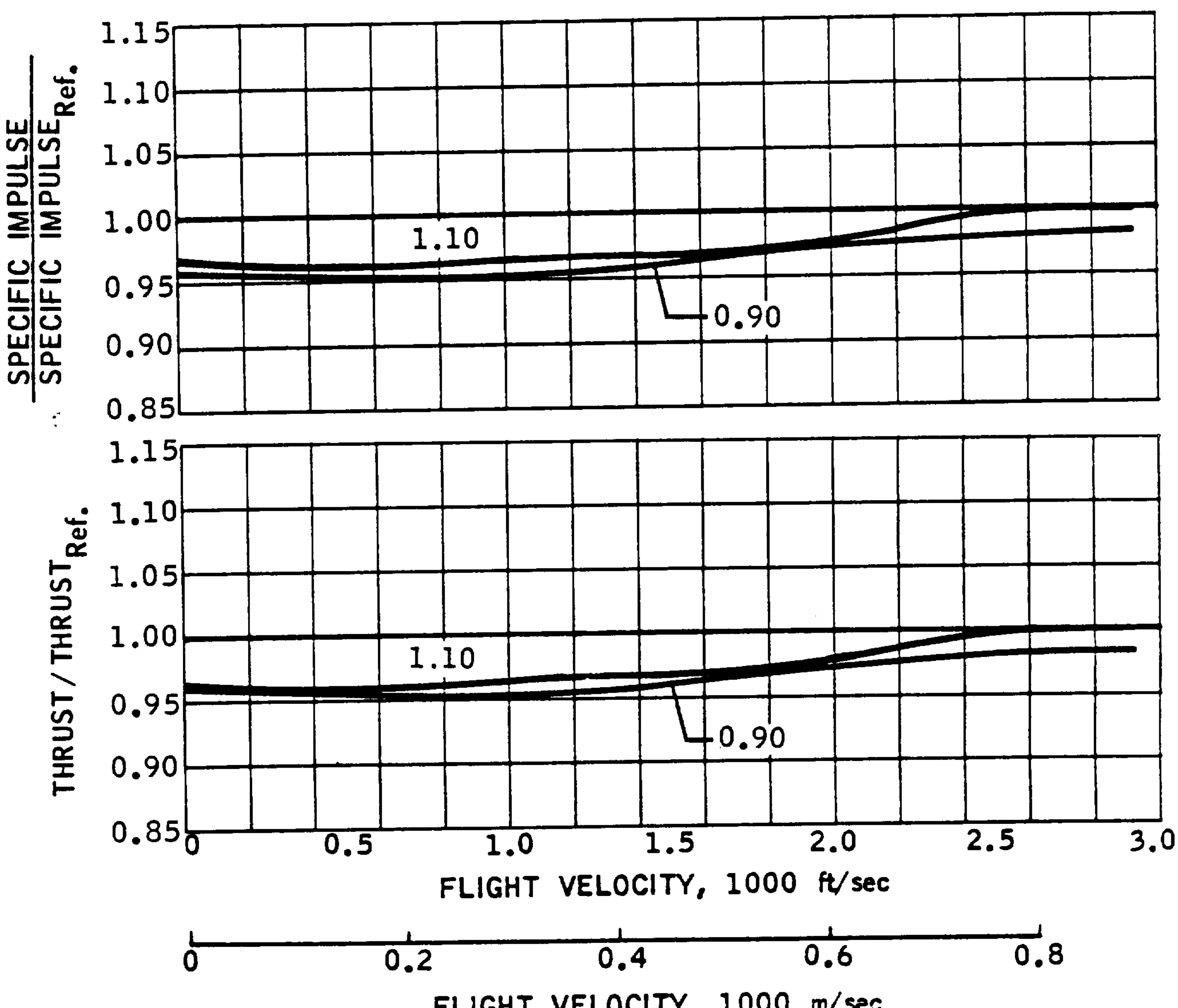

[redacted]

PRIMARY ROCKET COMBUSTION EFFICIENCY EFFECT
EJECTOR MODE

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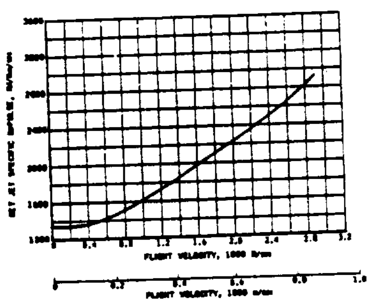

Eng. No. 22

Baseline

$\eta_c^* = 0.975$

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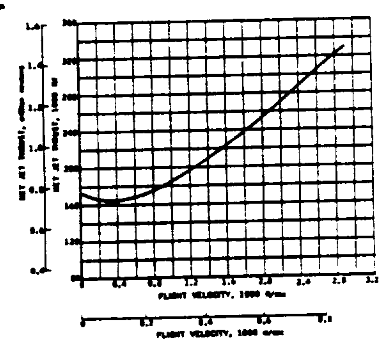

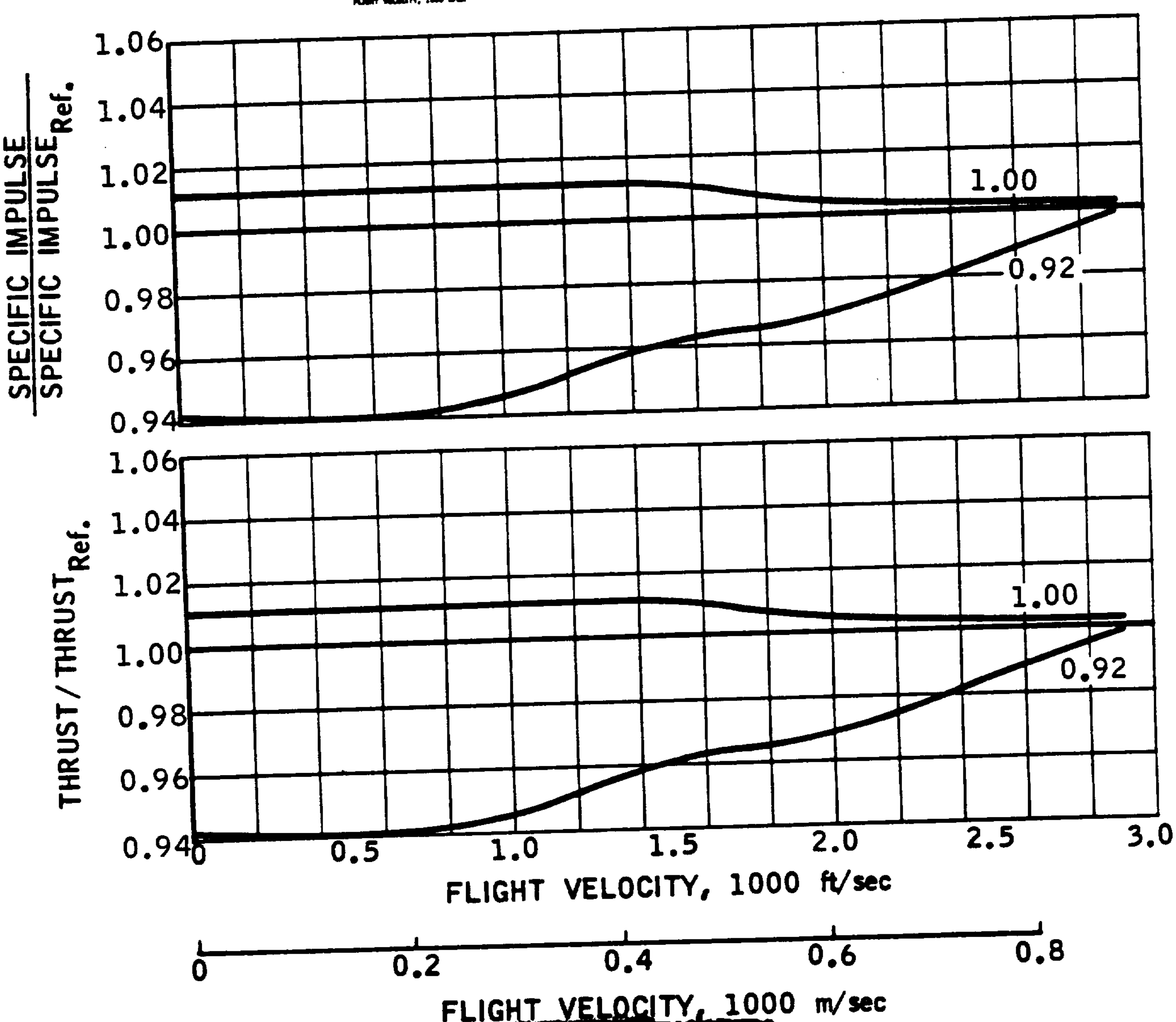

[redacted]

PRIMARY ROCKET NOZZLE EFFICIENCY EFFECT EJECTOR MODE

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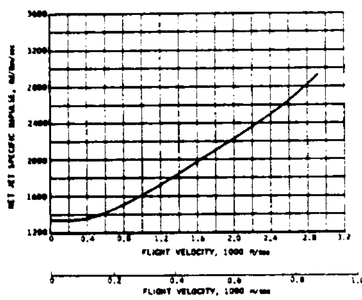
BASELINE SPECIFIC IMPULSE EJECTOR MODE



Eng. No. 22

Baseline

$\eta_N = 0.98$

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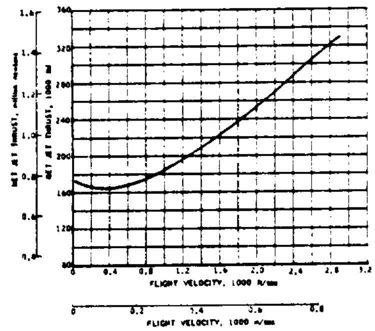
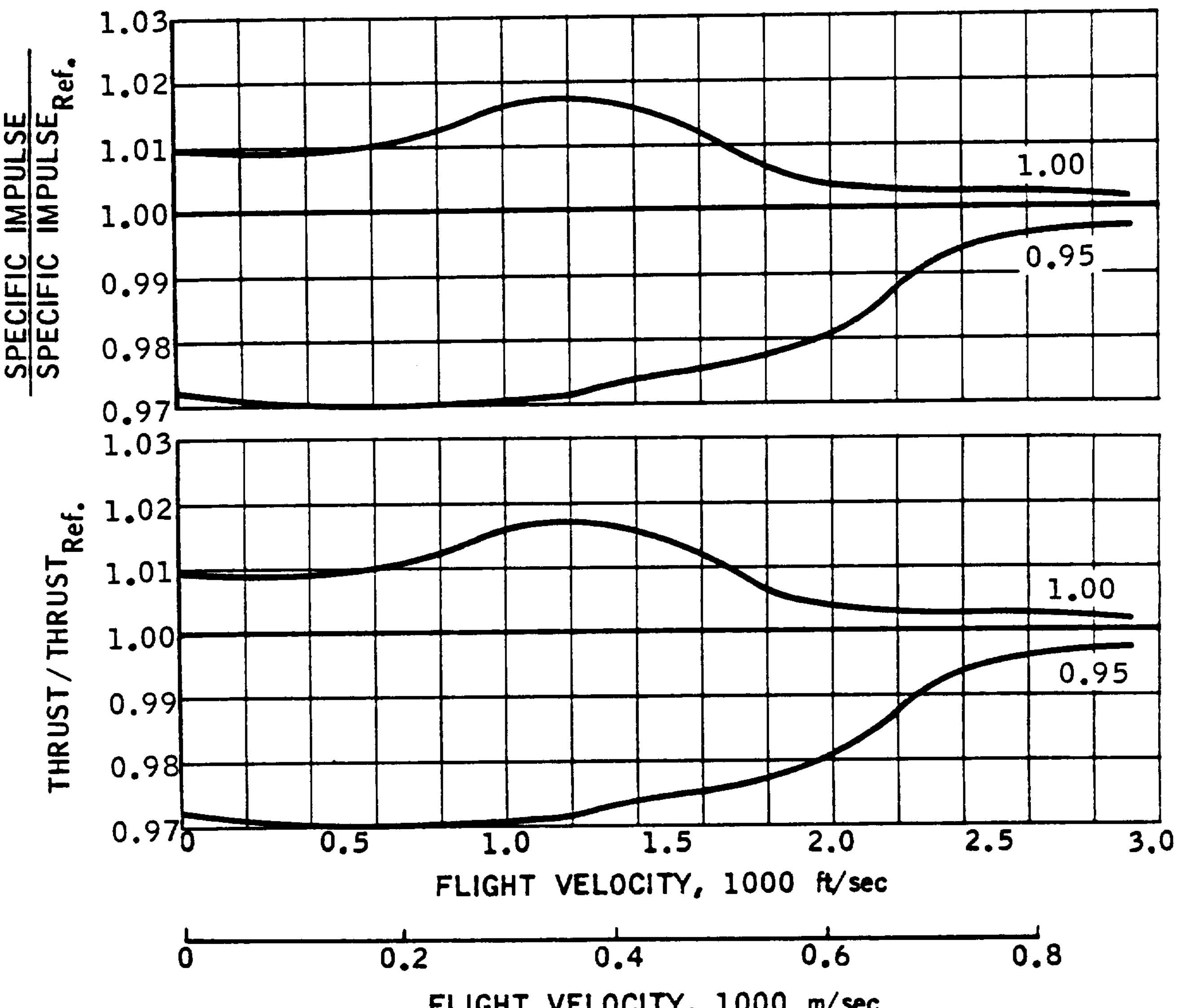
BASELINE THRUST EJECTOR MODE





MIXING EFFICIENCY EFFECT
EJECTOR MODE

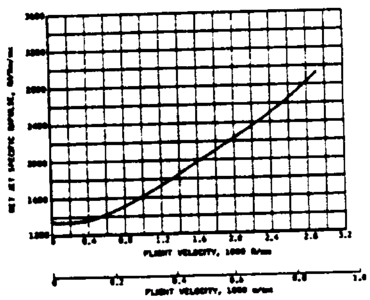
Page 145

BASELINE SPECIFIC IMPULSE EJECTOR MODE

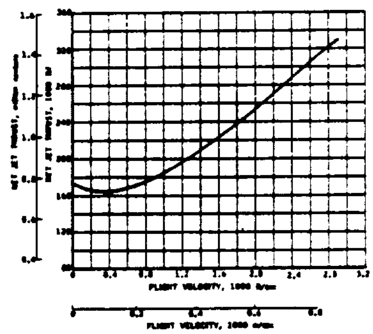
Page 146

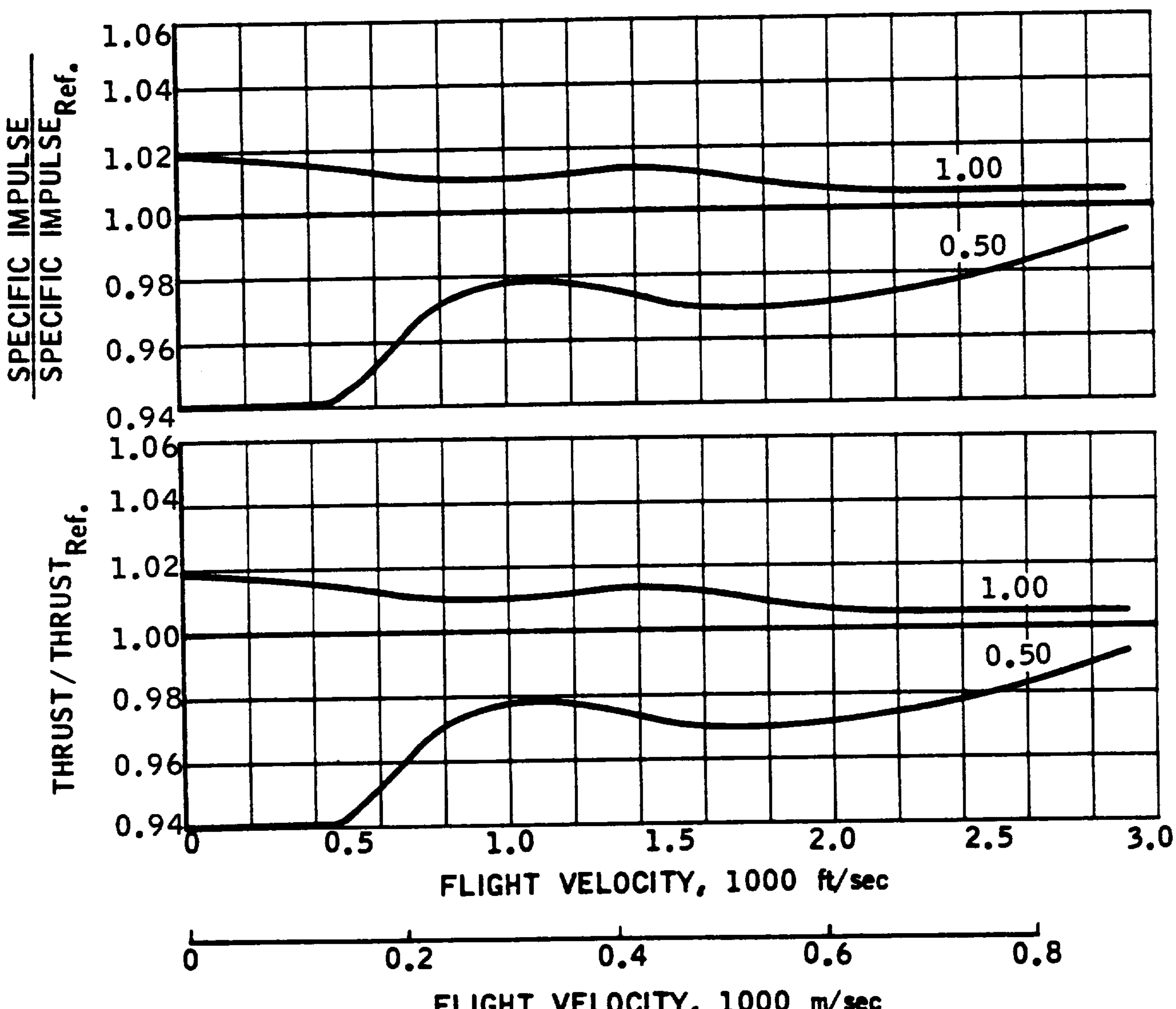
BASELINE THRUST EJECTOR MODE

Eng. No. 22



Baseline
$\eta_M = 0.80$





[redacted]

HEAT EXCHANGER EQUIVALENCE RATIO EFFECT
EJECTOR MODE

Eng. No. 22

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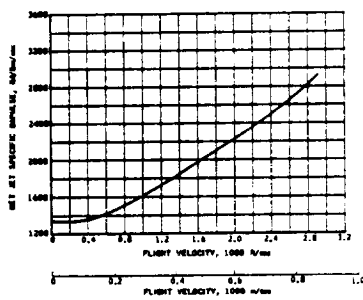
Eng. No. 22
BASELINE SPECIFIC IMPULSE
EJECTOR MODE



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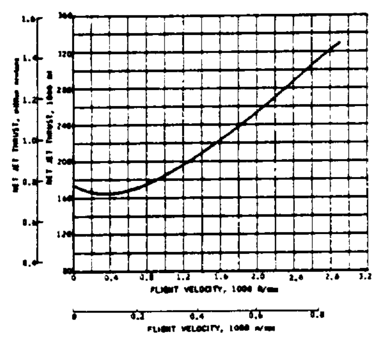
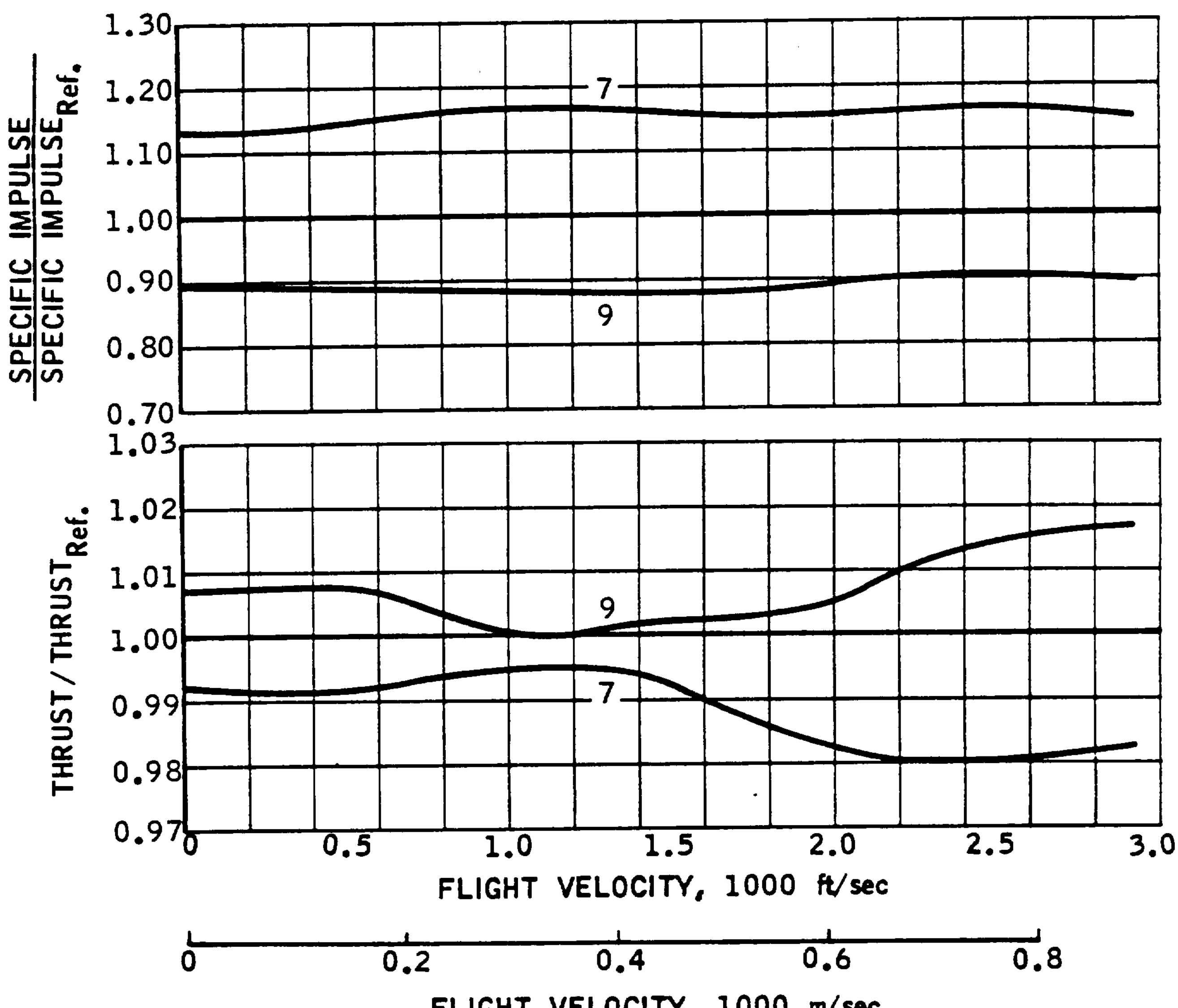
Eng. No. 22
BASELINE THRUST
EJECTOR MODE



Baseline
ϕ_{HX}
Figure F
(Page 153)



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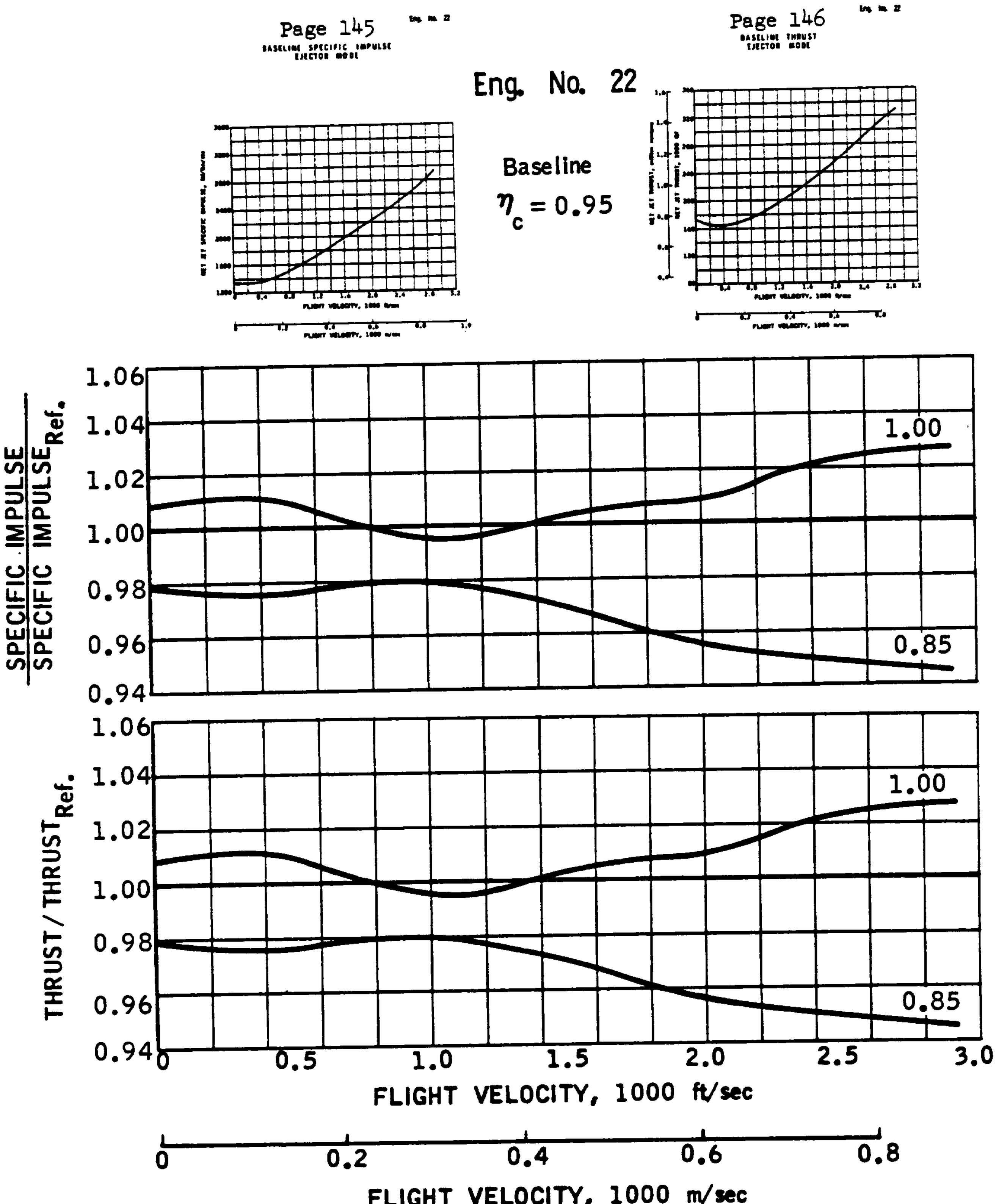
AFTERBURNER COMBUSTION EFFICIENCY EFFECT
EJECTOR MODE



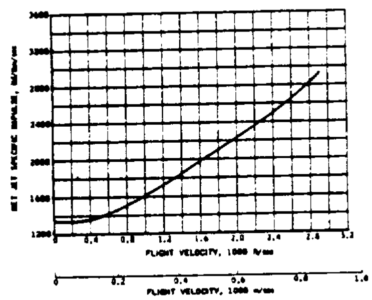
[redacted]

[redacted]

EXIT NOZZLE EFFICIENCY EFFECT
EJECTOR MODE

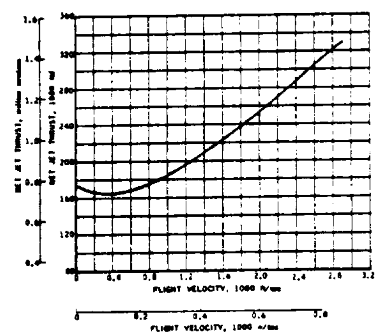
Page 145

BASELINE SPECIFIC IMPULSE EJECTOR MODE



Page 146

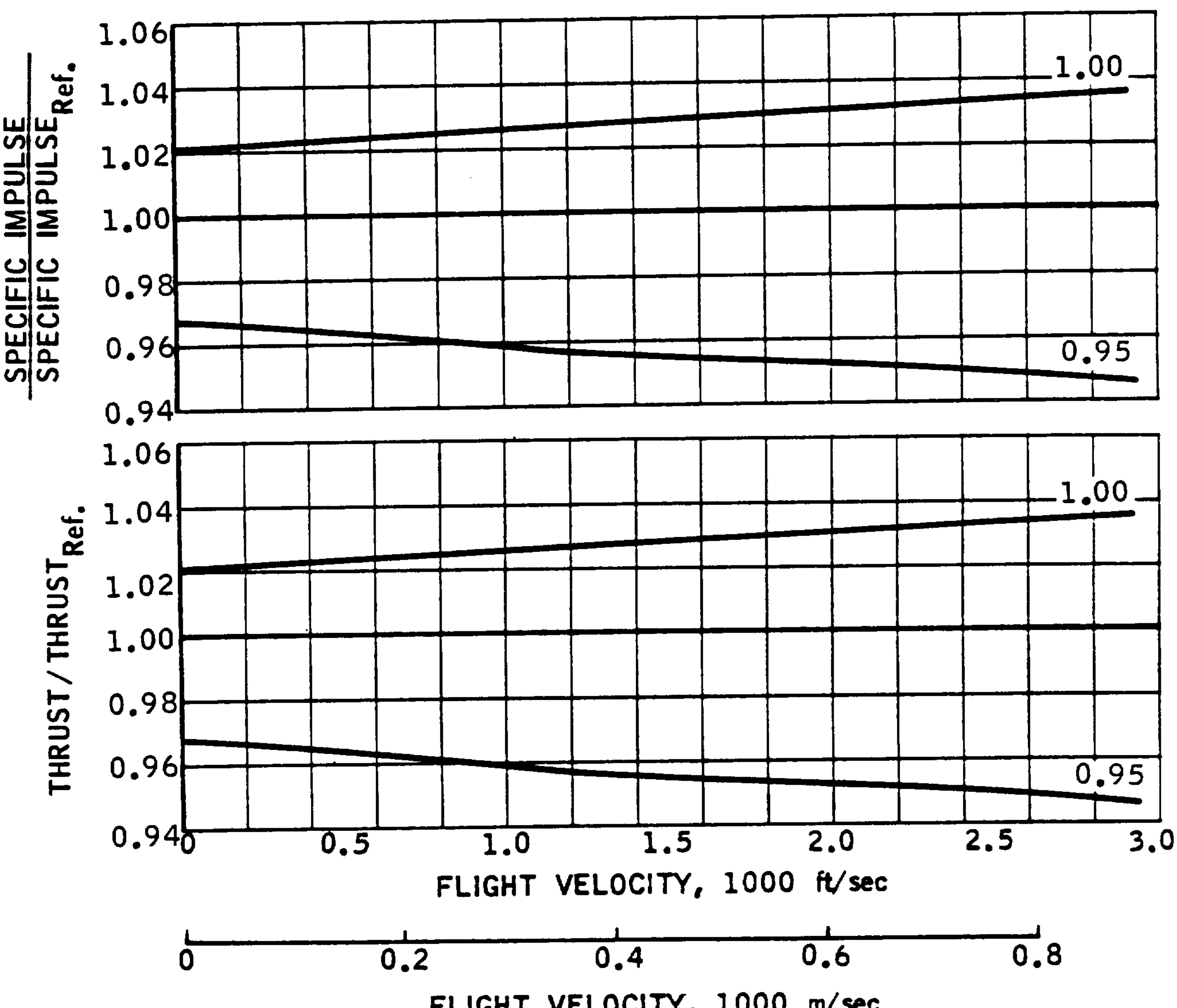
BASELINE THRUST EJECTOR MODE



Eng. No. 22

Baseline

$\eta_N = 0.98$

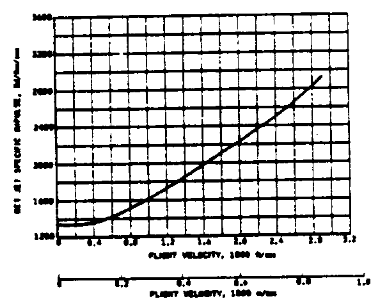


[redacted]

EXIT NOZZLE AREA RATIO EFFECT
EJECTOR MODE

Page 145

BASELINE SPECIFIC IMPULSE EJECTOR MODE



Eng. No. 22

Baseline

A_6/A_5:
Figure J
(Page 157)

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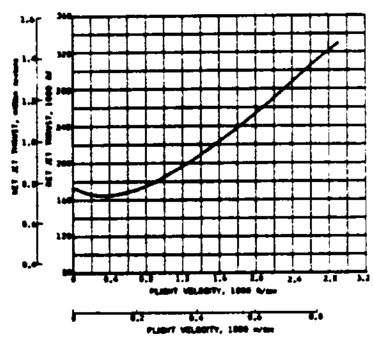
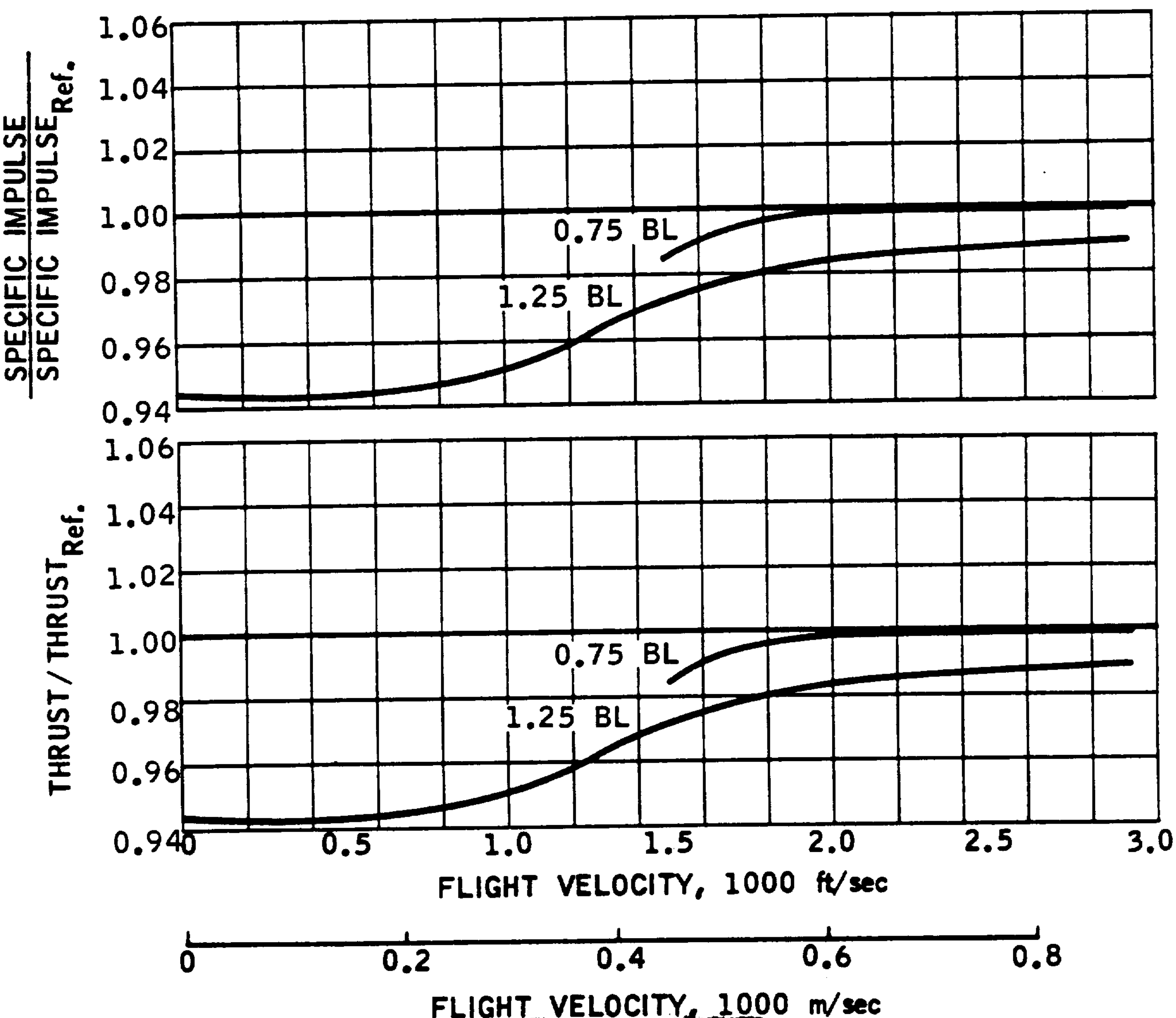
BASELINE THRUST EJECTOR MODE





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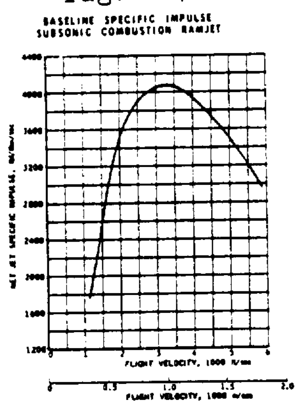
INLET PRESSURE RECOVERY EFFECT
RAMJET MODE

Page 147



Eng. No. 22

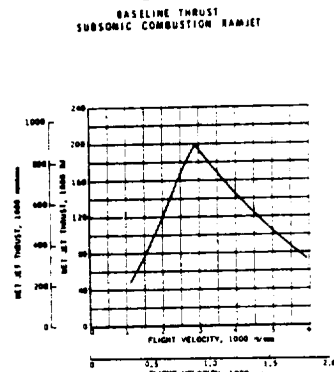
Baseline

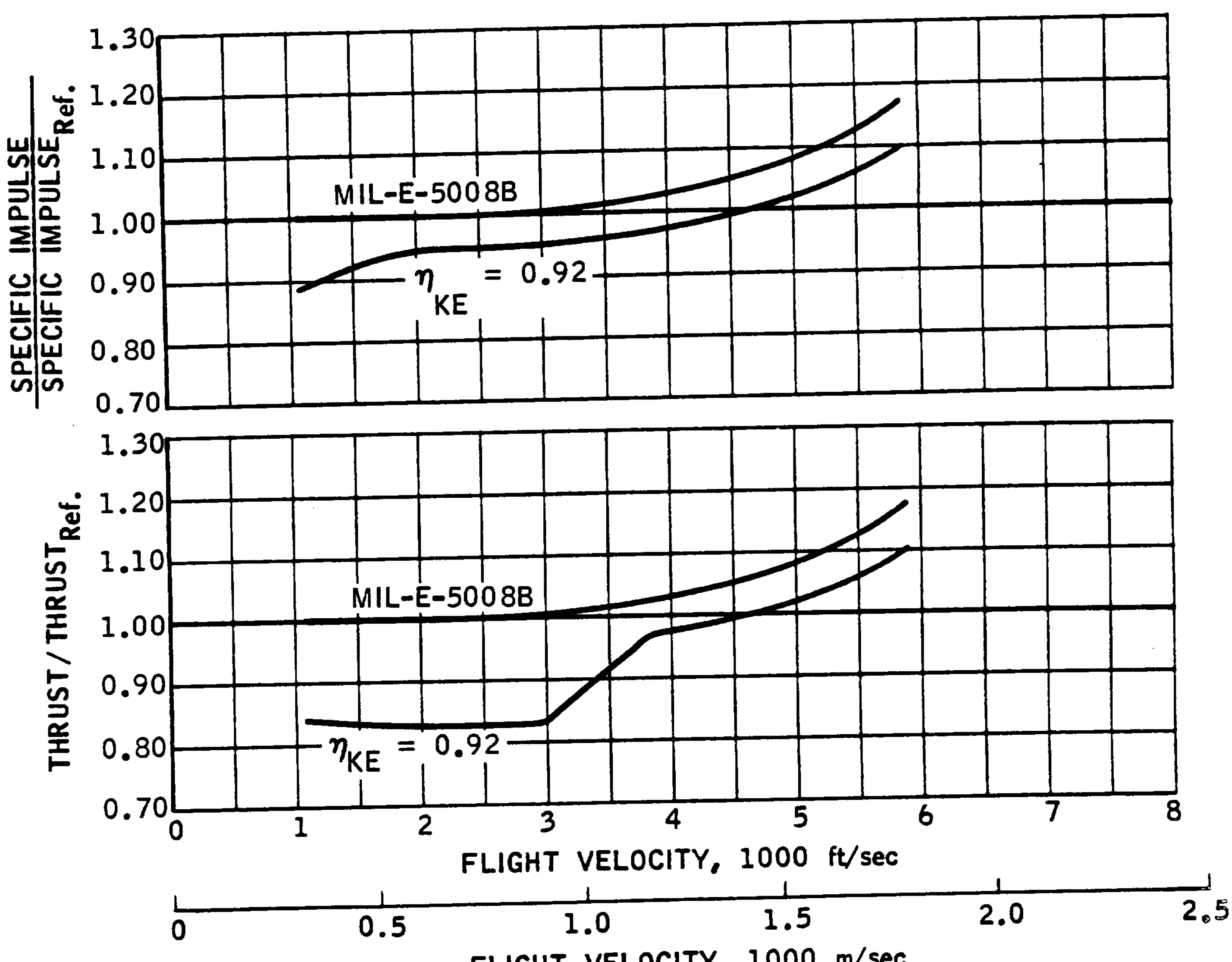
P_{T_2}/P_{T_0}:

Figure E

(Page 152)

Page 148





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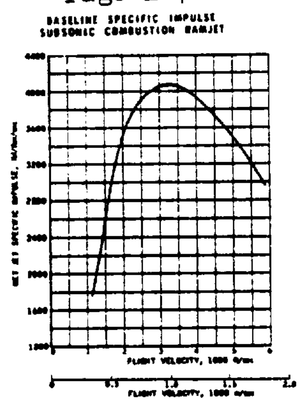
COMBUSTOR EQUIVALENCE RATIO EFFECT RAMJET MODE

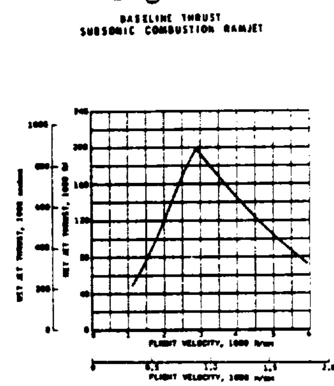
Page 147

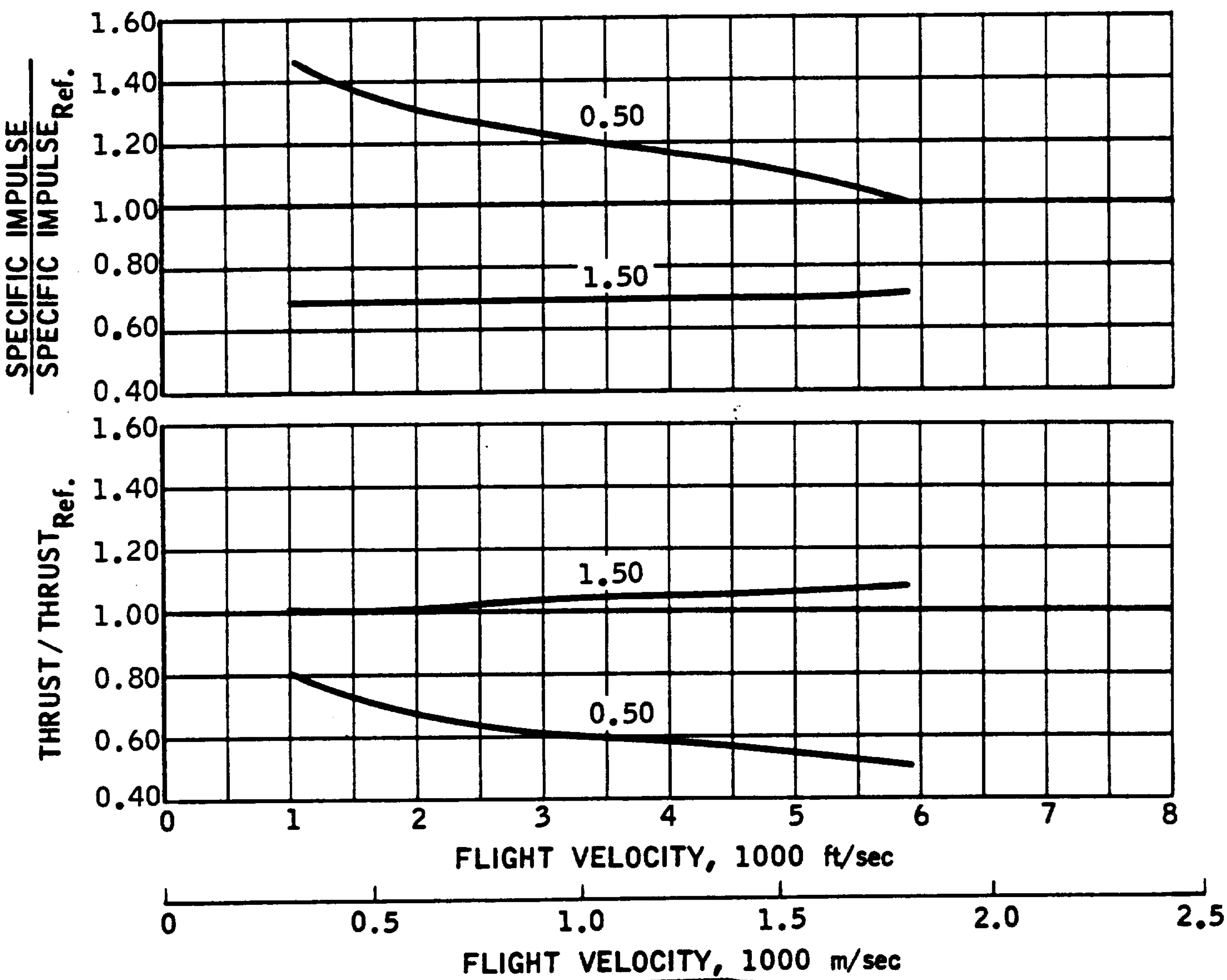


Eng. No. 22

Baseline
$\phi = 1.00$

Page 148

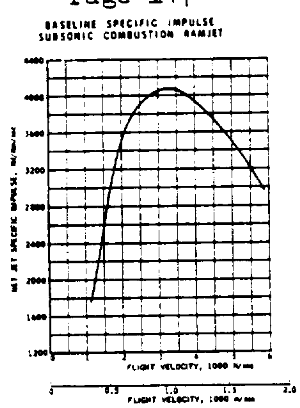




[redacted]

COMBUSTOR COMBUSTION EFFICIENCY EFFECT
RAMJET MODE

Page 147

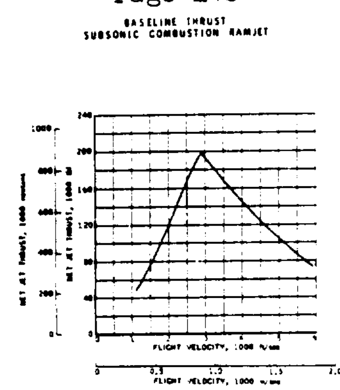


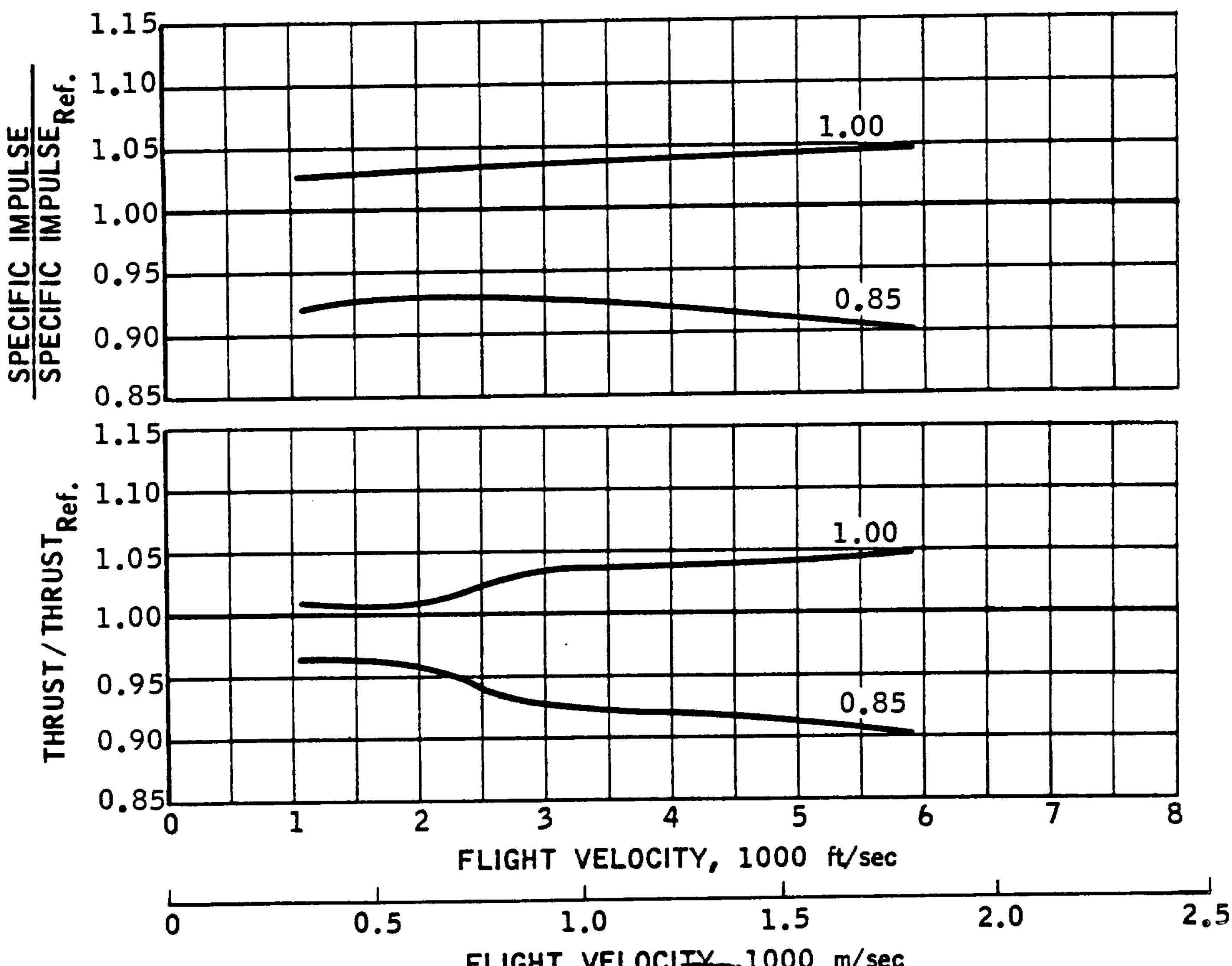
Eng. No. 22

Baseline

$\eta_c = 0.95$

Page 148





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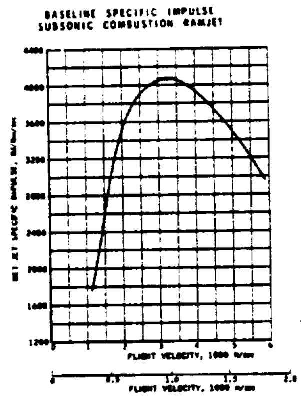
EXIT NOZZLE EFFICIENCY EFFECT
RAMJET MODE

Page 147

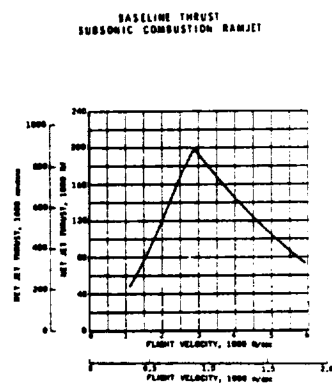


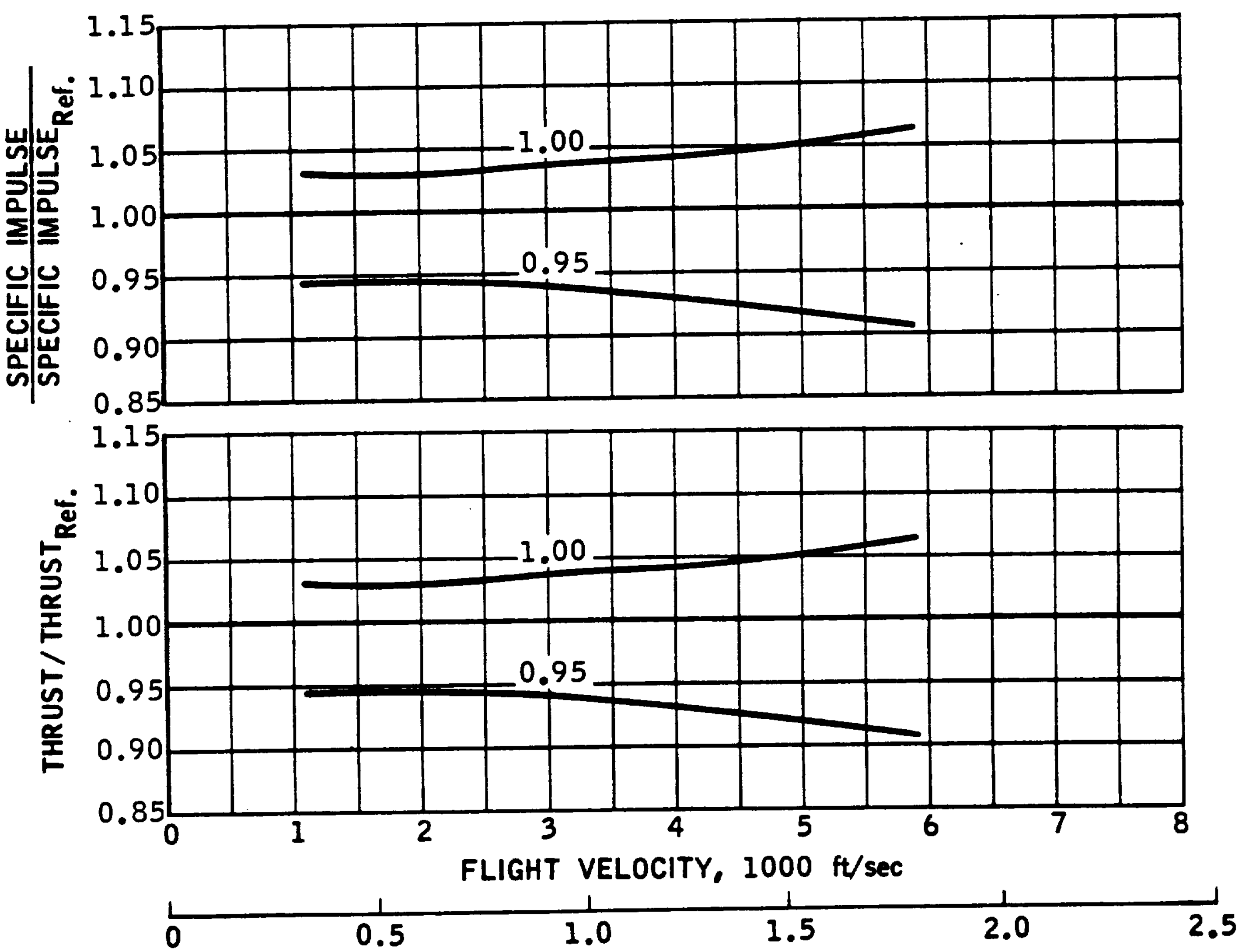
Eng. No. 22

Baseline

$\eta_N = 0.98$

Page 148





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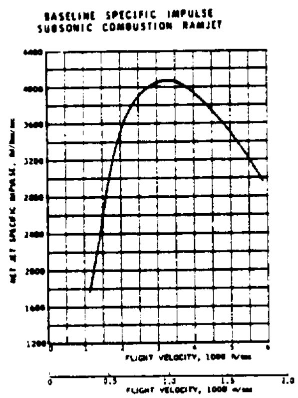
EXIT NOZZLE AREA RATIO EFFECT
RAMJET MODE

Page 147

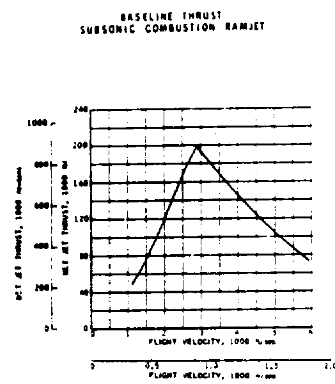


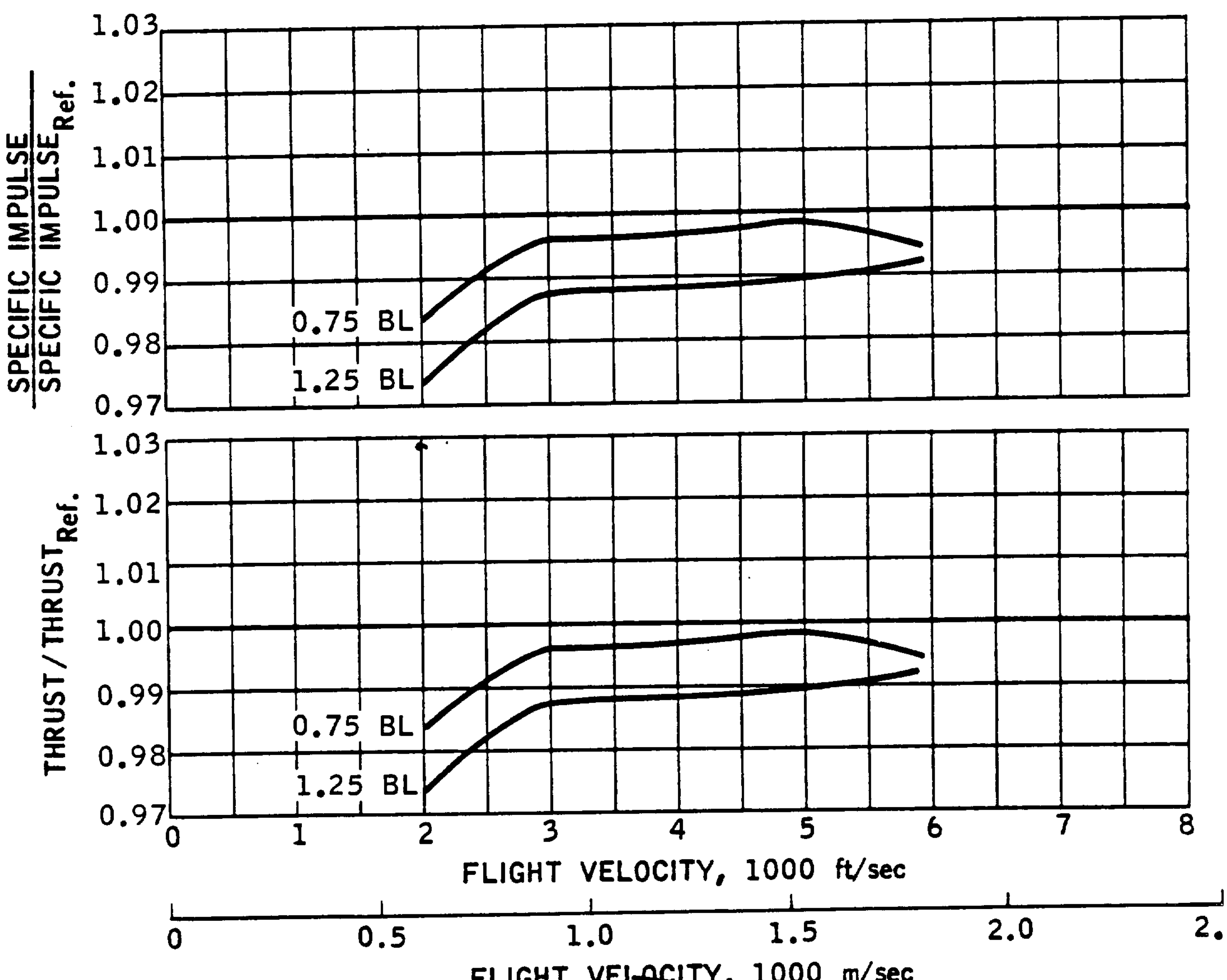
Eng. No. 22

Baseline

A_6/A_5:
Figure K
(Page 158)

Page 148





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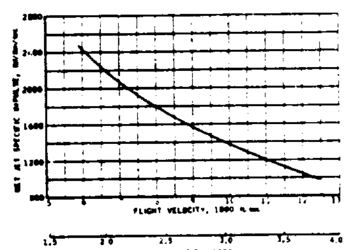
INLET PRESSURE RECOVERY EFFECT
SCRAMJET MODE

Page 149 Eng. No. 22

BASELINE SPECIFIC IMPULSE
SUPERSONIC COMBUSTION RAMJET

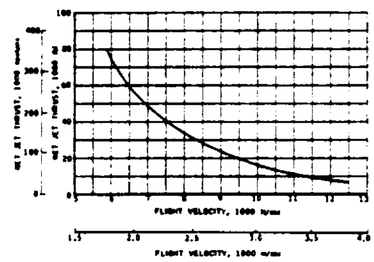


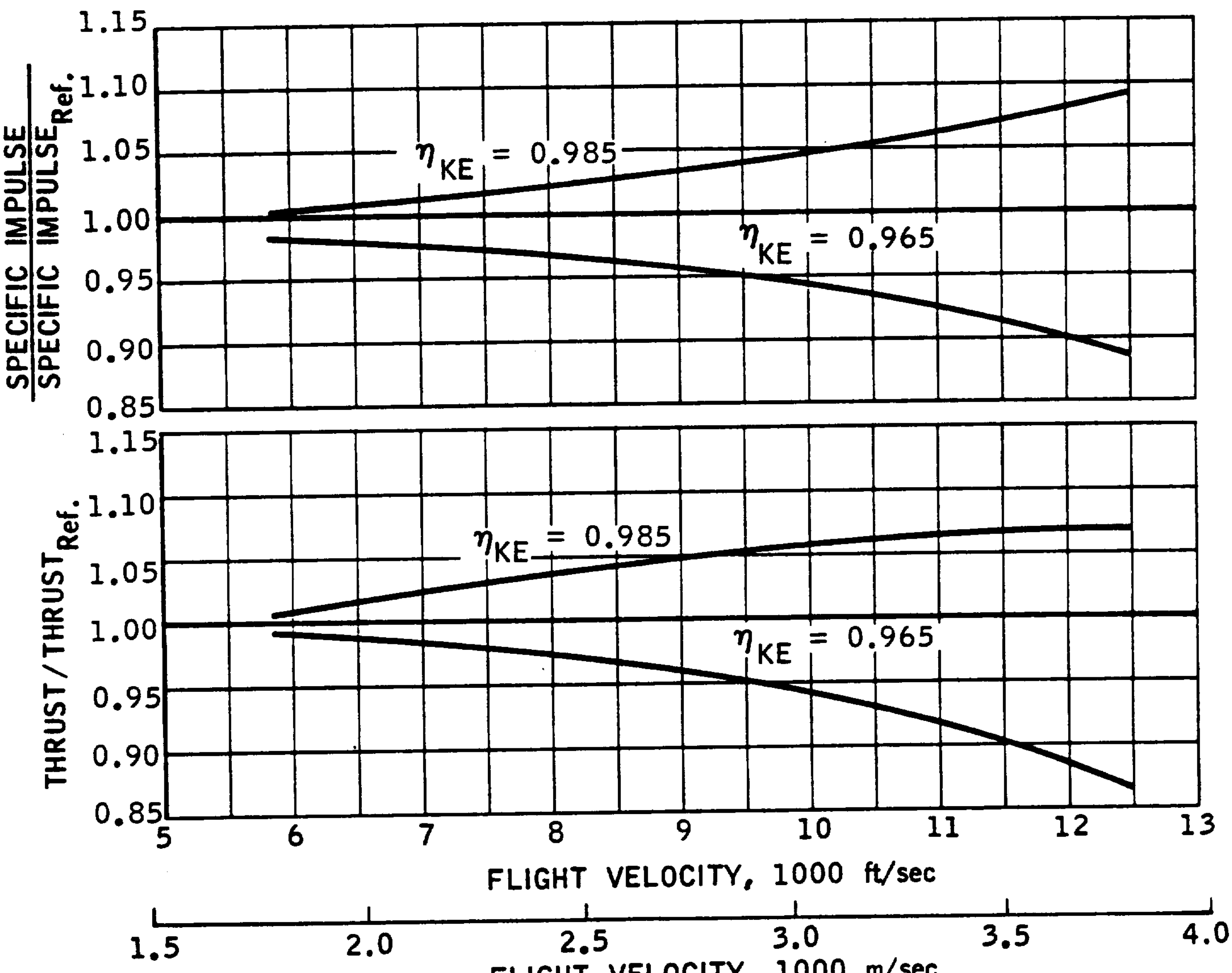
Eng. No. 22

Baseline
P_{T_2}/P_{T_0}:
Figure L
(Page 159)

Page 150 Eng. No. 22

BASELINE THRUST
SUPERSONIC COMBUSTION RAMJET





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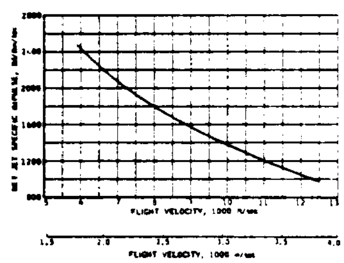
COMBUSTOR EQUIVALENCE RATIO EFFECT
SCRAMJET MODE

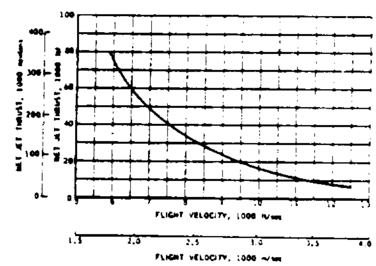
Page 149 Eng. No. 22

BASELINE SPECIFIC IMPULSE
SUPERSONIC COMBUSTION RAMJET



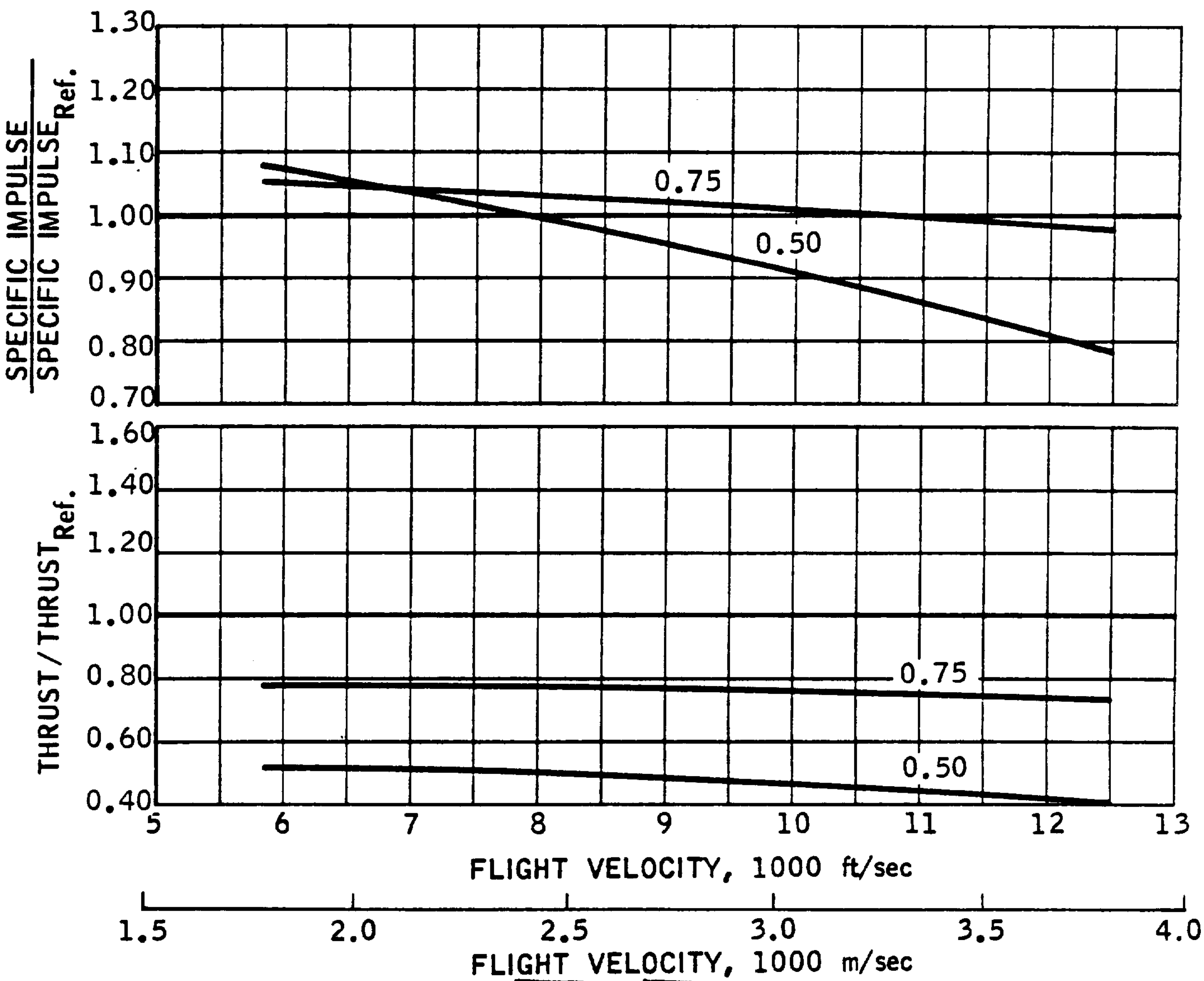
Page 150 Eng. No. 22

BASELINE THRUST
SUPERSONIC COMBUSTION RAMJET



Eng. No. 22

Baseline
$\phi = 1.00$

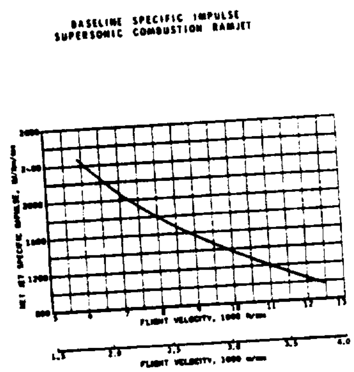


[redacted]

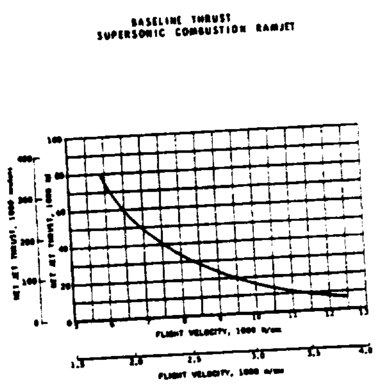
THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

COMBUSTOR COMBUSTION EFFICIENCY EFFECT
SCRAMJET MODE

Page 149



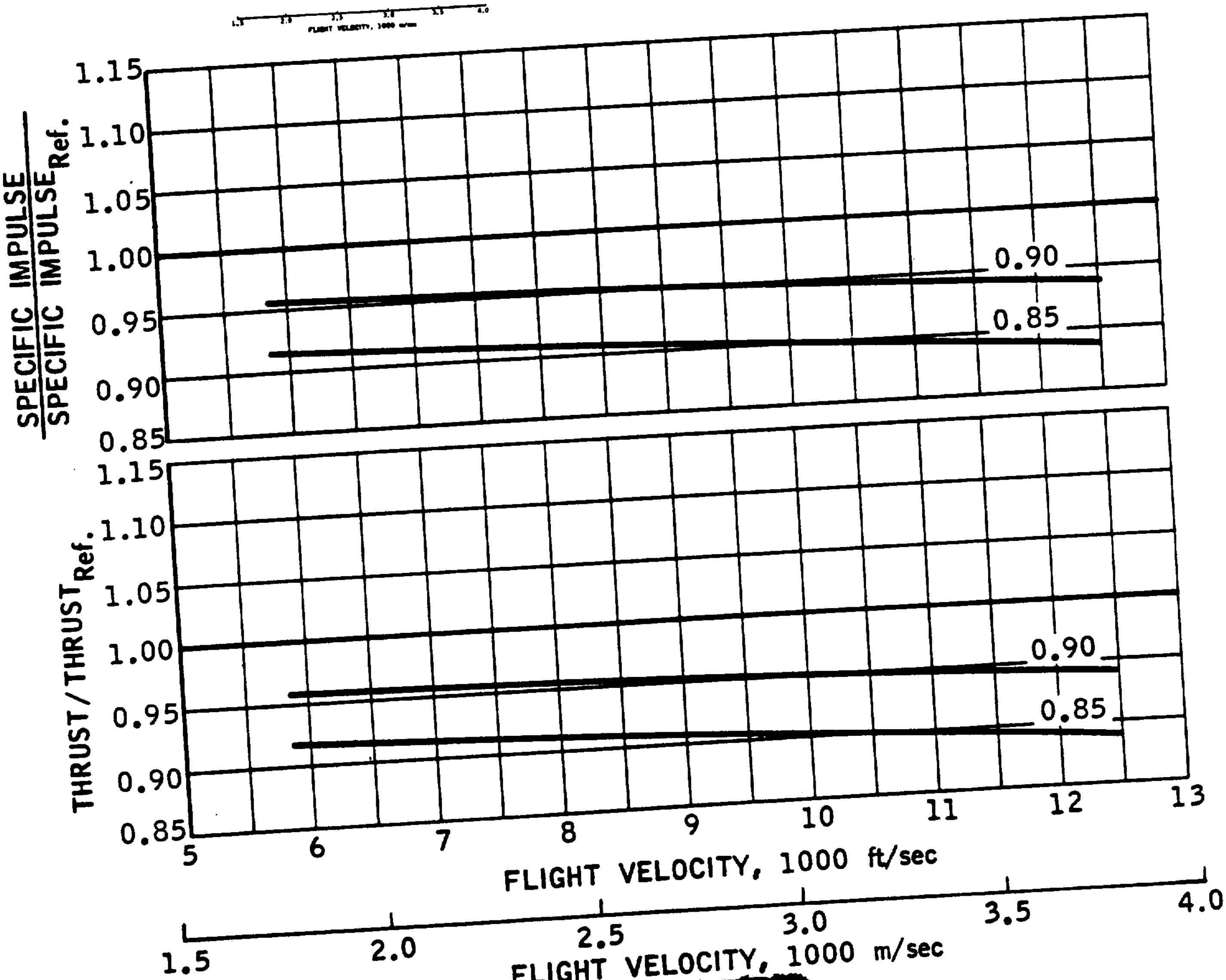
Page 150



Eng. No. 22

Baseline

$\eta_c = 0.95$



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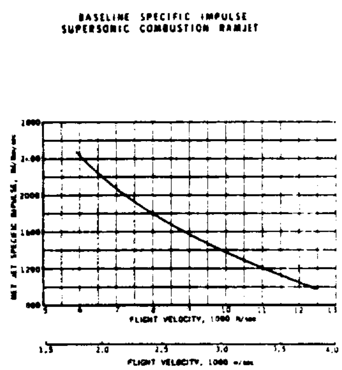
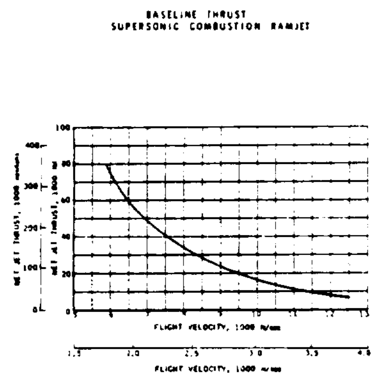
EXIT NOZZLE EFFICIENCY EFFECT
SCRAMJET MODE

Page 149 Eng. No. 22

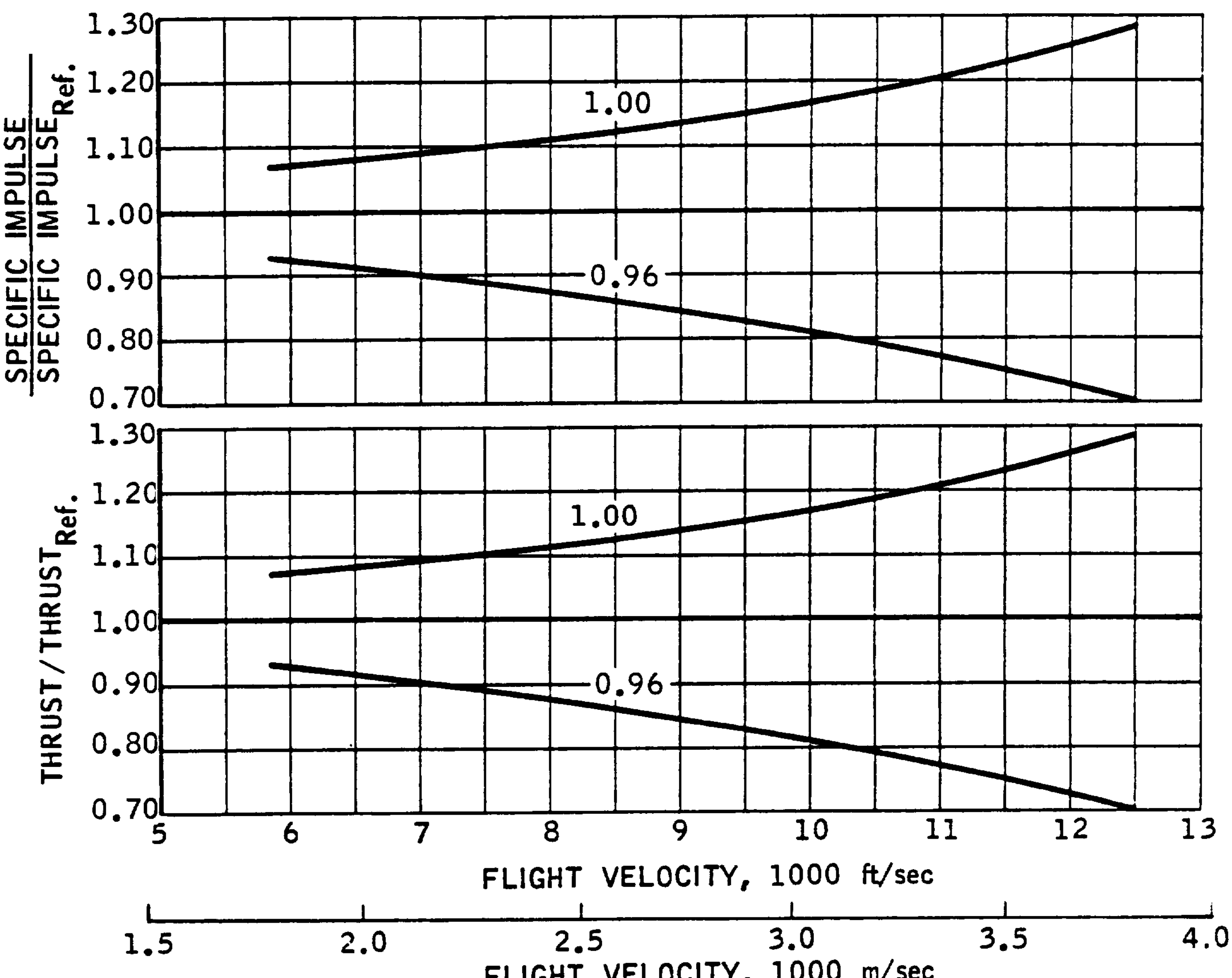


Page 150 Eng. No. 22



Eng. No. 22

Baseline
$\eta_N = 0.98$



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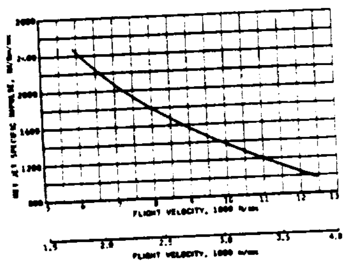
THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

EXIT NOZZLE/INLET COWL AREA RATIO EFFECT
SCRAMJET MODE

Page 149 Eng. No. 22

BASELINE SPECIFIC IMPULSE
SUPERSONIC COMBUSTION RAMJET



Eng. No. 22

Baseline

$A_6/A_C = 1.50$

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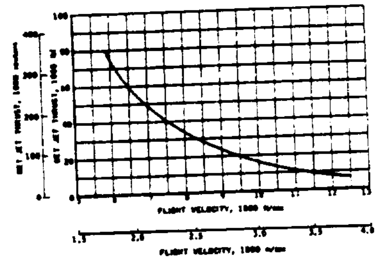
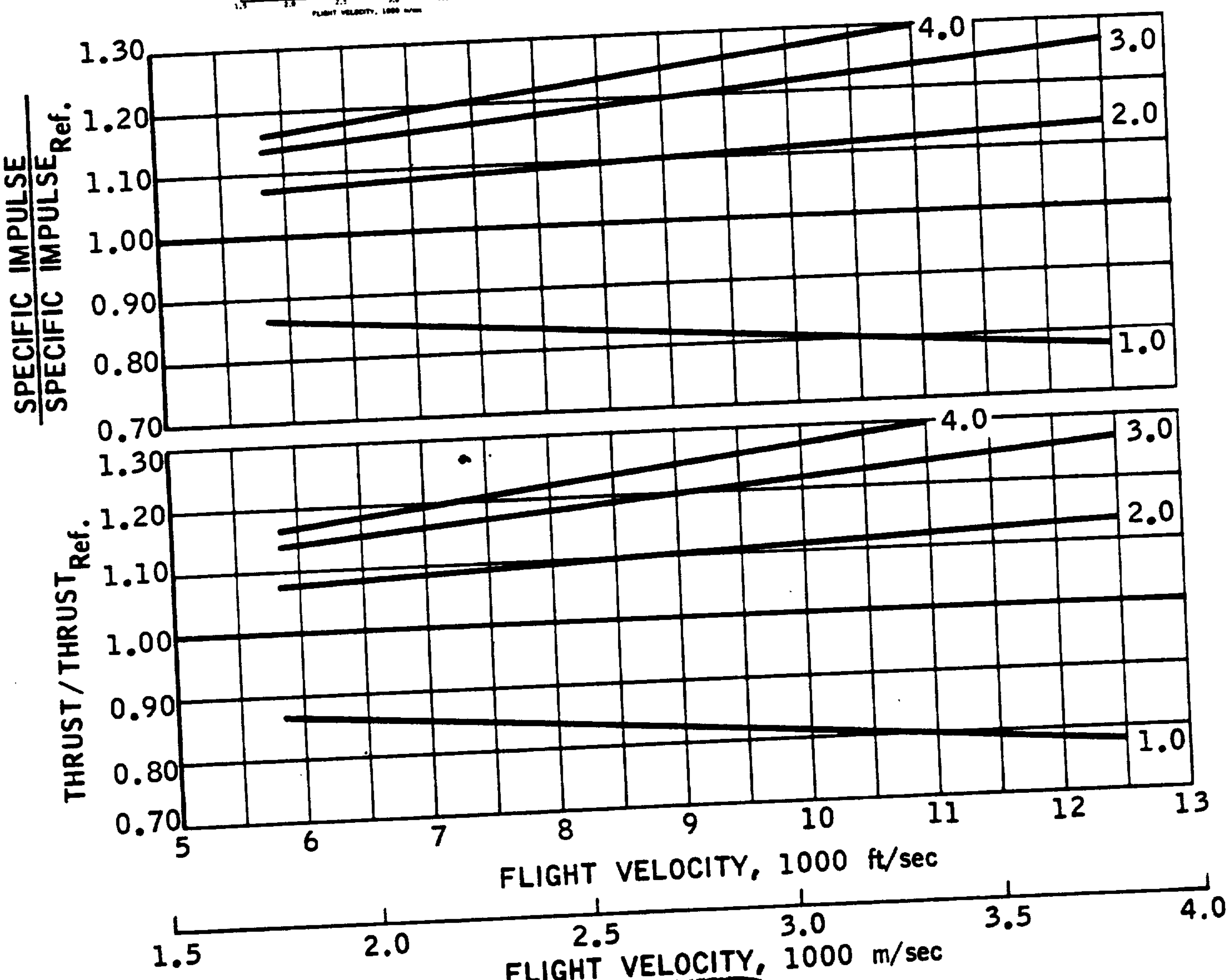
BASELINE THRUST
SUPERSONIC COMBUSTION RAMJET





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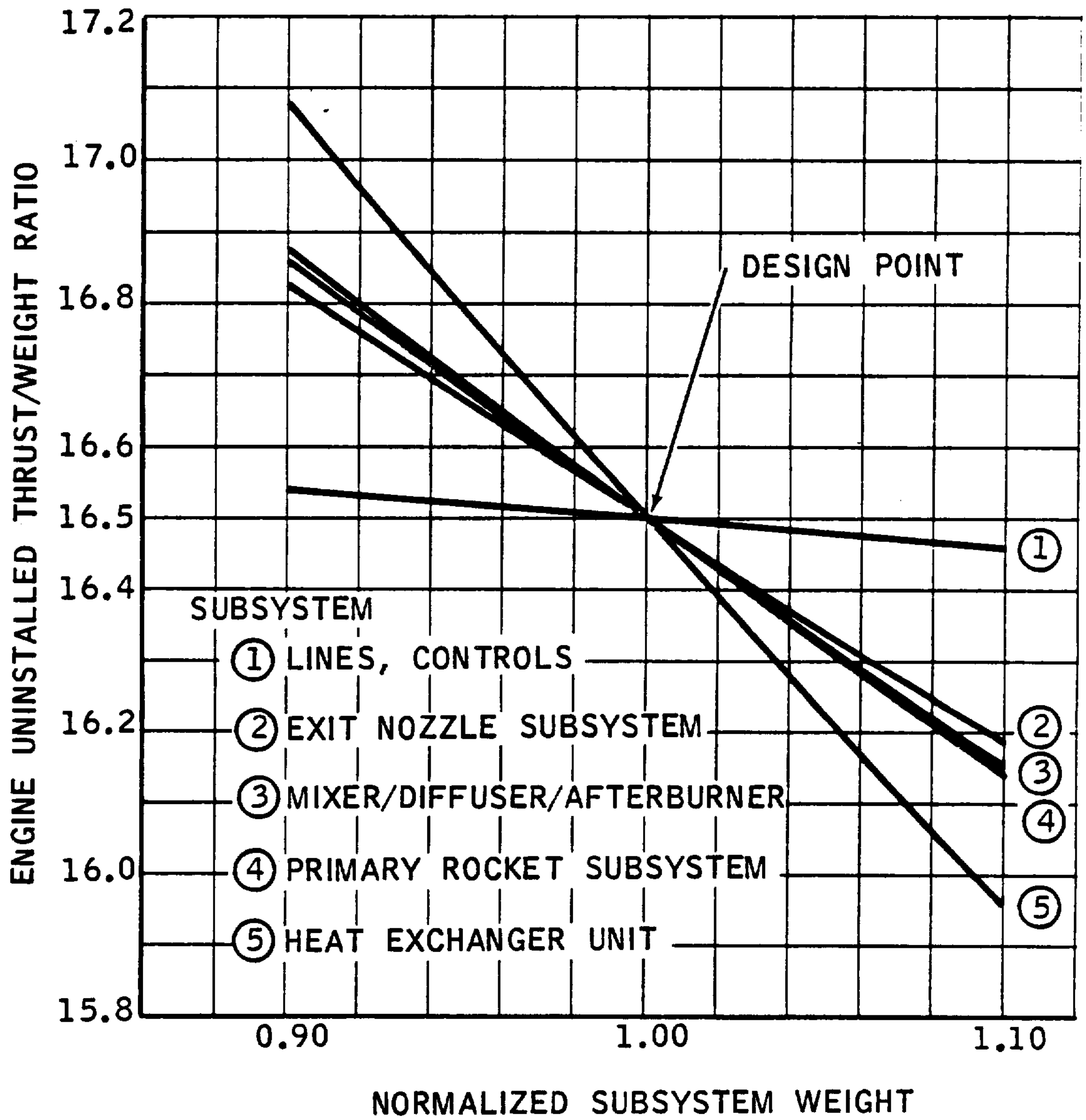
EFFECT OF SUBSYSTEM WEIGHT VARIATION ON ENGINE THRUST/WEIGHT

± 10 PER CENT WEIGHT VARIATION



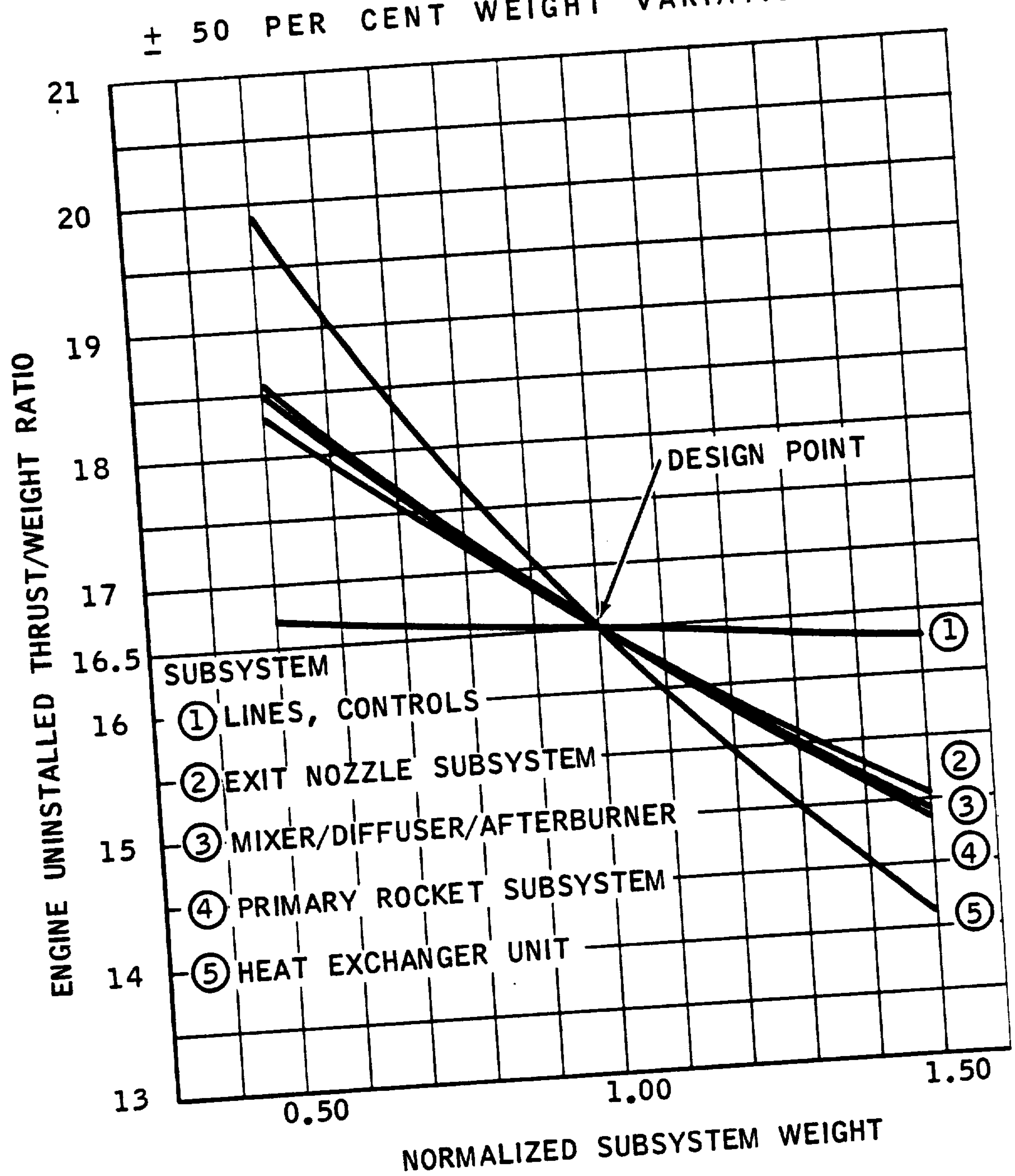
[redacted]

THE Marquardt CORPORATION VAN NUYS, CALIFORNIA

Eng. No. 22

EFFECT OF SUBSYSTEM WEIGHT VARIATION ON ENGINE THRUST/WEIGHT

± 50 PER CENT WEIGHT VARIATION



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